Aquatic Environment Impact Ratings

A Method for Evaluating SSRB Flow Scenarios

RED DEER River Case Study

Alberta

Aquatic Environment Impact Ratings

A Method for Evaluating SSRB Flow Scenarios

- Red Deer River Case Study -

Prepared by:

Lori Goater[1]

C. Wendell Koning[2]

Allan G.H. Locke[1]

John M. Mahoney[3]

Andrew J. Paul[1]

[1]Fish and Wildlife Division, Alberta Sustainable Resource Development, Cochrane, Alberta

[2]Regional Environmental Management, Southern Region, Alberta Environment, Calgary, Alberta

[3] Water Management Operations Division, Alberta Environment, Lethbridge, Alberta

July 12, 2007

(revised Nov. 4, 2008)

Aquatic Environment Impact Ratings: A Method for Evaluating SSRB Flow Scenarios—Red Deer River Case Study

ISBN No. 978-0-7785-7649-5 (Printed Edition)

ISBN No. 978-0-7785-7650-1 (On-line Edition)

CITATION

Goater, L., C.W. Koning, A.G.H. Locke, J.M. Mahoney, and A.J. Paul. 2007. Aquatic environment impact ratings: a method for evaluating SSRB flow scenarios—Red Deer River case study. Alberta Environment and Alberta Sustainable Resource Development, Alberta. 47 pp.

Report available at:

Alberta Government Library – Great West Life Site
6th Floor, 9920 108 Street
Edmonton AB T5K 2M4

Email: env.library@gov.ab.ca

ACKNOWLEDGEMENTS:

The following report contains a summary of *Instream Flow Needs Determinations for the South Saskatchewan River Basin* (Clipperton et al. 2003). That report forms the essence of the methods used here to assess various flow scenarios for the Red Deer River. We thank Darcy McDonald (Alberta Environment) for conducting the water quality modeling; Tom Tang (Alberta Environment) and Kent Berg (Alberta Environment) for clarifying amongst the numerous Red Deer River Flow scenarios developed; and the Alberta Environment staff in Lethbridge for contributing office space and support.

EXECUTIVE SUMMARY:

One of the essential background studies required to inform the preparation of a water management plan for the South Saskatchewan River Basin was a determination of the instream flow needs (IFN) that would provide a high level of protection for the aquatic ecosystem of all mainstem reaches in the basin. A technical team was formed to carry out this study. Based on current science, the technical team used a holistic approach to determine IFN based on the natural flow paradigm (the ecological need for natural flow variation). To do this, IFN were determined using natural benchmarks of seasonal and annual variability in flow magnitude, frequency, timing, duration and rate of change. To accommodate biological and hydrological variability placed within the constraints of the water planning model, the resulting IFN were developed on a weekly time-step and consisted of a maximum instantaneous percent reduction coupled with an ecosystem base flow (the flow below which no water abstraction is recommended) (Clipperton et al. 2003).

The IFN of four ecosystem components were determined in order to represent the full range of flow requirements for the aquatic ecosystem. 1) Water quality IFN were to manage instream temperatures, dissolved oxygen concentrations and assimilation of ammonia effluent from waste water treatment plants; 2) fish habitat IFN were to protect physical instream habitats using select sport fish species as a surrogate; 3) riparian vegetation IFN were for the recruitment, growth, and survival of poplar forests; and 4) channel maintenance IFN were to support geomorphological processes involving the movement of streambed, floodplain, and channel substrates. A combined IFN for the aquatic ecosystem was determined by integrating the maximum flow requirements across the four ecosystem components. This work is fully described in Clipperton et al. (2003).

For the Red Deer River, water regulators were interested in understanding the ecosystem impacts associated with alternative water-use scenarios relative to the fully protective IFN determined in Clipperton et al. (2003). To assess these alternative flow management scenarios for the Red Deer River, an impact ratings methodology was developed based on a qualitative and categorical scale of ecosystem effects. The scale consisted of four categories: slight, marginal, serious and extreme effects. The boundary between slight and marginal effects was defined as the IFN determined in Clipperton et al. (2003). The categorization of alternative flow scenarios was first developed for each of the four ecosystem components used by Clipperton et al. (2003). Based on measured deviations from the IFN determination within each of the ecosystem components, independent impact ratings were developed. A final overall aquatic ecosystem rating was then developed based on the four individual ratings. Methods used to make these ratings are described in this report.

Six flow scenarios were analyzed for the Red Deer River: natural flow, present use of existing licenses, instream flow needs (based on Clipperton et al. 2003), increased use of existing licenses, new licenses with high water conservation objective (WCO), and new

licenses with proposed WCO. Impact ratings for these scenarios are summarized in the final table of this report (Table 26). By definition, the natural flow scenario resulted in no effect on the Red Deer River. Present use of existing licenses and the instream flow needs determination (Clipperton et al. 2003) were predicted to have only slight impacts on the aquatic environment. The remaining three scenarios (increased use of existing licenses, new licenses with high WCO, and new licenses with proposed WCO) were predicted to result in serious impacts to the aquatic ecosystem with measurable declines in condition or abundance of stream biota.

TABLE OF CONTENTS:

LIST OF FIGURES:

LIST OF EQUATIONS:

LIST OF TABLES:

I - Introduction

In 1990, the Province of Alberta introduced a Water Management Policy for the South Saskatchewan River Basin (SSRB). One of the essential background studies required to inform the preparation of a water management plan (WMP) for the South Saskatchewan River Basin (SSRB) was the determination of instream flow needs for a fully protected aquatic environment. The steering committee for the SSRB WMP appointed a technical committee (the IFN Technical Team) to develop instream flow needs (IFN) determinations to be used in the Water Resources Management Model (WRMM). Senior members of the IFN Technical Team included Kasey Clipperton (Alberta Sustainable Resource Development), Wendell Koning (Alberta Environment), Allan Locke (Alberta Sustainable Resource Development), John Mahoney (Alberta Environment), and Bob Quazi (Alberta Environment).

Using current science, the team's objective was to determine instream flow needs that would fully protect the ecological integrity and biodiversity of the aquatic environment in the SSRB without regard to management constraints. Full protection meant that implementing the IFN would produce no measurable environmental decline due to anthropogenic causes over the long term. The team initially produced separate flow determinations for four ecosystem components: water quality, fish habitat, riparian vegetation, and channel maintenance. The component determinations were then combined to produce an integrated IFN to provide full protection to the mainstem riverine environment throughout the SSRB.

The integrated IFN determinations were applied to river reaches across the SSRB (Figure 1) for use in comparative scenario evaluations in the WRMM. In addition to providing a fully protective IFN determination, the steering committee requested an ecosystem impact ratings method specifically to evaluate alternative flow management scenarios for the Red Deer River. The objective of this report is to document the methods used in evaluating these alternative flow management scenarios for the Red Deer River.

The report is organized into two parts. Part one contains brief technical summaries of methods used to establish IFN determinations in the SSRB that provide for full protection of the aquatic environment. The reader is referred to Clipperton et al. (2003) for a comprehensive discussion of the background and in-depth details of the methods used to make these IFN determinations. The purpose of summarizing these techniques within the following document is to provide a basis for the methodology used to evaluate impacts from alternative flow management scenarios. The second part of this document explains the impact ratings methodology and demonstrates its application using example flow management scenarios applied to seven reaches of the Red Deer River (Table 1).

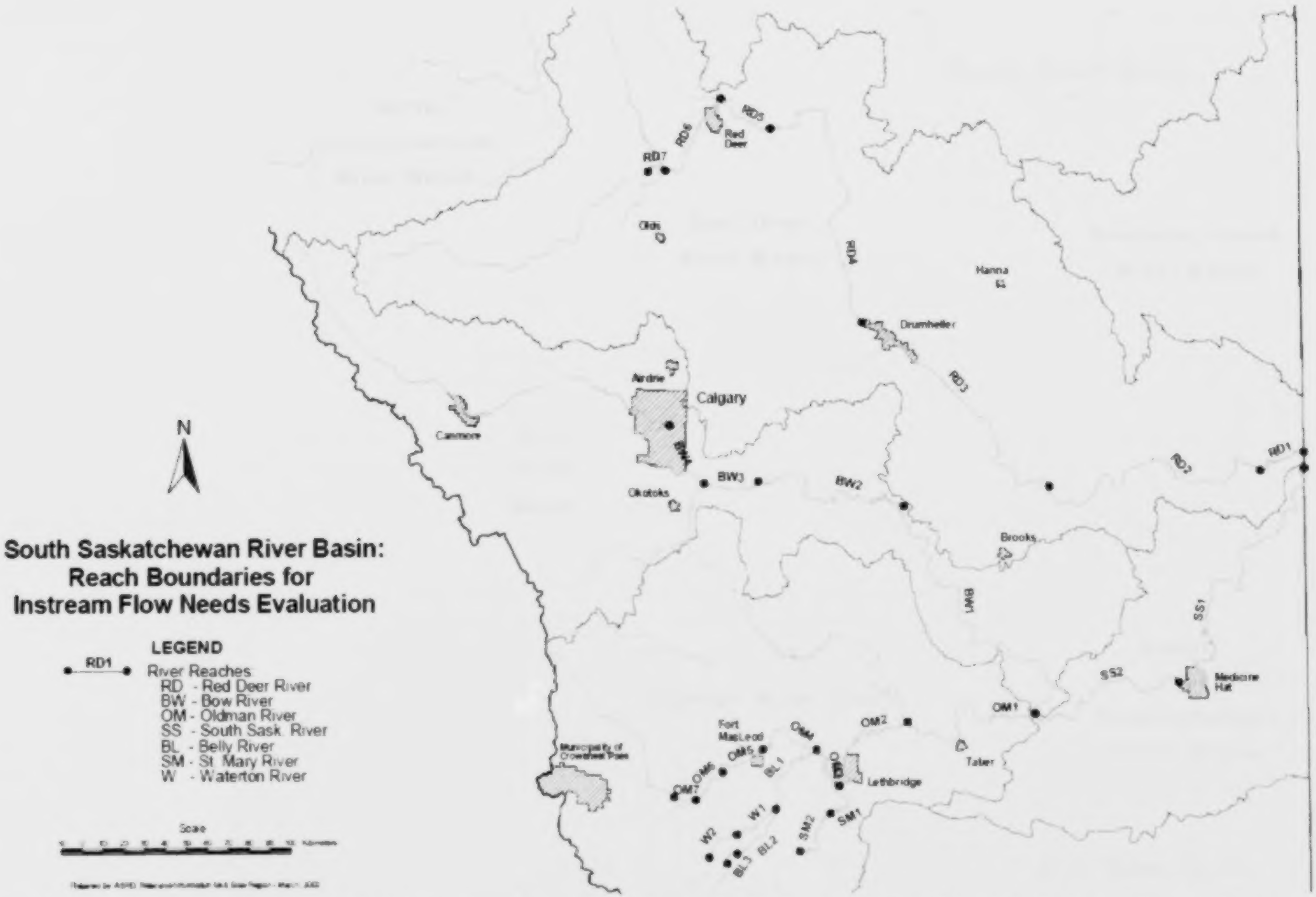

Figure 1. Map of reach boundaries for IFN evaluation on rivers in the South Saskatchewan River Basin in southern Alberta (reproduced Figure 4.2. from Clipperton et al. 2003).

Table i. Red Deer River reach boundaries and gauging stations. Note: * indicates flows were generated by Alberta Environment (2001) and not an actual gauge.

Reach Boundaries	Reach Code	WSC Gauge	Gauge Location
Dickson Dam – Medicine River confluence	RD7	05CB007	below Dickson Dam
Medicine River confluence – Blindman River confluence	RD6	05CC002	near Red Deer
Blindman River confluence – SAWSP[1] diversion	RD5	05CD004	near Nevis
SAWSP[1] diversion – western boundary of Drumheller	RD4	GRDBIG*	near Big Valley
western boundary of Drumheller – western boundary of Dinosaur Prov. Park	RD3	05CE001	near Drumheller
western boundary of Dinosaur Prov. Park – Bindloss gauging station	RD2	GRDJEN*	near Jenner
Bindloss gauging station – Saskatchewan / Alberta border	RD1	05CK004	near Bindloss

[1] – *Special Areas Water Supply Project*

II - IFN Determinations

A. Background:

Streamflow is a master variable in riverine ecosystems (Annear et al. 2004). The interaction of flow with the physical environment affects all aspects of water quality and river geomorphology, in turn affecting instream and riparian habitats and their associated assemblage of aquatic and riparian organisms. The natural flow paradigm is a widely supported concept that natural flow variability (measured by magnitude, frequency, timing, duration and rate of change within and across years) is required to maintain the ecological integrity of riverine ecosystems (Poff et al. 1997, Richter et al. 1997).

Because natural flows shape aquatic and riparian environments, the best way to fully protect the natural riverine environment indefinitely would be to supply the natural flow regime. This is not a practical management option because human demand for water resources dictates that water is needed "outside" the river channel, or in greater than natural amounts (e.g. hydropower requires increased flows in the fall/winter). Demands on streamflow for consumptive uses (municipal, agricultural, industrial, and domestic) result in flow reductions or temporal alterations to the natural pattern of flow. Thus, there is a requirement to define the IFN necessary to support riverine ecosystems at a stated level of protection (objective), and to predict ecosystem impacts when IFN are not met.

There is no single or widely accepted method to determine IFN. Recognizing the complex interrelation of elements in riverine ecosystems, the SSRB IFN was developed based on the objective of providing full protection to the aquatic environment by integrating flow requirements of four ecosystem elements: water quality, fish habitat, riparian vegetation, and channel maintenance. IFN were set as limits to flow reduction and were based on the premise that natural flows provide complete ecosystem protection.

IFN determinations for the SSRB were subject to several limitations. The methods used were constrained to information available at the time that the determinations were made (Clipperton et al. 2003). Naturalized (reconstructed natural) flow datasets (Alberta Environment 2001) were modeled for the SSRB by accounting for water stored, diverted, or returned, and adding or subtracting these allocations to recorded streamflows. Flow data (observed and naturalized) were evaluated using a weekly time-step to be compatible with the concurrent water-plan modeling. Weekly flow exceedence* data were based on the historic 83 years (1912-1995) of observed and naturalized streamflow records that were available (gauges for the Red Deer River are listed in Table 1). The historic flow data was used as a surrogate for future flow patterns without consideration of climate change or other impacts outside of direct human uses.

* Weekly flow exceedence (or duration) is the probability of a given flow magnitude being equaled or exceeded during a specific week of the year; a weekly exceedence (or duration) curve is the graphic representation of the relationship between exceedences (x-axis; ranked order) and the range of flow magnitudes (y-axis) observed during a specific week.

B. IFN determinations for ecosystem components:

1. IFN for Water Quality:

The IFN for water quality are focused on managing instream temperature, dissolved oxygen (DO), and ammonia in some reaches (reaches subject to effluent loading downstream from major cities). Most other water quality variables (especially contaminants like metals and pesticides) are most efficiently managed using source control measures, rather than by flow manipulation and so were not directly considered here.

Fish injury and mortality are associated with high water temperatures and low DO. The guidelines for instream dissolved oxygen and temperature for the protection of selected fish in the SSRB are summarized in Table 2. The acute maximum temperatures for most sport fish species lie between 22 and 29 degrees Celsius, and the chronic (7-day average) maximum temperature is between 18 and 24 degrees Celsius (Taylor and Barton 1992). The guideline for fish protection against acute level deficits in DO is 5 mg/l, and against 7-day average chronic level deficits is 6.5 mg/l (Alberta Environment 1999).

Determinations of IFN are essential to managing stream temperatures and DO. Stream temperatures tend to track ambient air temperatures but are buffered somewhat by increases in steamflow. Dissolved oxygen levels are associated with water temperature (oxygen becomes less soluble at increased temperatures) and oxygen demand, which is largely driven by nutrient loading. Nutrient loading from point (e.g. city wastewater treatment plant outfalls) and non-point (e.g. runoff from agricultural, urban, timber harvest, industrial, and recreational activities) sources can be reduced by bio-assimilation, dilution, sedimentation, volatilization, or transport downstream. These processes can be disrupted if minimum streamflows are inadequate. Additionally, higher flows are occasionally required to dislodge organic sediments and aquatic vegetation (macrophytes) to reduce oxygen demand. Macrophytes and algal growth can exert considerable oxygen demand during night-time periods in late summer when growth can be prolific, and during the winter (under ice, with less light penetration and less reaeration) when the biomass decays. Flow augmentation beyond natural flows may even be necessary for dilution of wastes, particularly during low-flow periods.

AGRA et al. (1995) used the Dynamic Stream Simulation and Assessment Model with temperature (DSSAMt) to provide initial water quality IFN values. Their modeling was carried out during the ice-free months of April through October at five locations (Fort Normandeau: reach RD6; Nevis: RD4/5; Big Valley: RD4; Jenner: RD2; and Bindloss: RD1). The model was calibrated with 1992 data, tested against 1983 data, and assessed for five incremental flow scenarios (10, 20, 25, 30, 40 m^3/s). Based on the frequencies of failure for the temperature criteria (Table 3), AGRA concluded that flows should not be dropped below 30 m^3/s below the Dickson Dam (25 m^3/s + 5 m^3/s margin of error) during the April-October period to minimize the harmful effects of high temperatures on fish. They also suggested that these flows would prevent violations of critical ammonia and DO levels under 1992 loading conditions. These types of modeling results are subject to

change over time, with advances in wastewater treatment technology (reduced loadings, i.e., less impact on the river) and increases in population and human activity in the watershed (increased loadings, i.e., greater impact on the river). A minimum flow requirement of 16 m^3/s was set for the winter period (November through March: weeks 1-13 and 44-52) to maintain minimum DO levels of 5.0 mg/L in the Red Deer River (Grant 1974)*. These IFN recommendations are summarized in Table 4.

More recently, AGRA's IFN values were refined using CE-QUAL-W2 (v.3-1)—a public domain model that was developed by the US Army Corps of Engineers, in cooperation with Portland State University under the supervision of Dr. Scott Wells. This two-dimensional, longitudinal/vertical model consists of directly coupled hydrodynamic and water quality transport models to provide state-of-the-art capabilities for modeling long and narrow water bodies exhibiting longitudinal gradients (such as rivers). This model is able to predict water surface elevations, velocities, and temperatures, and can simulate a large number of water quality constituents. For the Red Deer River these included total dissolved solids, bacteria, phosphorus, ammonium, nitrate-nitrite, dissolved and particulate organic matter, CBOD (Carbonaceous Biological Oxygen Demand), algae, epiphyton, and dissolved oxygen.

The CE-QUAL-W2 model was calibrated for the Red Deer River based on hydrological conditions observed during 1997 to 2001. It was set up to run continuously through two-year cycles (1997-98; 2001-02), outputting data 10 times per day to allow evaluation of both diurnal (e.g. temperature and dissolved oxygen) and longer-term (e.g. seasonal) cycles. Simulated temperature, dissolved oxygen, and nutrient concentrations were found to compare very well with measured data (personal communication, Darcy McDonald 2007). Based on "worst case" meteorological and loading conditions from 2001 (the 10th warmest year in the previous 54 years), a range of flows was modeled to refine weekly IFN flows for each reach. The highest flows predicted to produce water quality guideline violations for DO, temperature, or nutrient concentrations in a given week were selected as the minimum IFN. The final determinations are summarized in Table 5.

* Assuming under-ice DO concentrations of at least 10.2 mg/l below the Dickson Dam, and a net oxygen depletion rate of 14,600 lb/day between the dam and Empress, Grant (1974) calculated that the minimum flow required to maintain DO levels of at least 5.0 mg/l would be 14,600 lb/day / (5.39 x (10.2-5.0 mg/l)) . = 520 ft^3/s (or 14.72 m^3/s) (note: 5.39 is a units conversion factor: 0.000002205 lb/mg x 86400 s/day / 0.035314667 ft^3/l). Considering data constraints, a safety factor of 10% was also applied, producing the final minimum winter flow requirement of 570 ft^3/s (or 16.14 m^3/s).

Table 2. Guidelines for instream dissolved oxygen and temperature for the protection of selected fish in the SSRB (Alberta Environment 1999, Taylor and Barton 1992).

Minimum DO criteria: (mg / L)	Acute (1 day average)	Chronic (7 day average)
All fish species	< 5	< 6.5

Maximum temperature criteria: (degrees C)	Acute (1 day average)	Chronic (7 day average)
Rainbow Trout	24	19
Brown Trout	25	20
Mountain Whitefish	22	18
Walleye / Sauger	29	24

Table 3. Frequency (% of days) that temperature criteria were exceeded (failed) from Apr. 1 through Oct. 30, 1992 for Red Deer River reaches (RD1 – RD7), for incremental flows from 10 to 40 $m^3 s$ (from AGRA 1995). Sampling sites associated with the reaches were: Dickson (0 km) = RD7; Fort Normandeau (47 km) = RD6; Nevis (140 km) = RD5; Big Valley (175 km) = RD4; and Jenner (444 km) = RD2. Values associated with the recommended minimum flow of 25 m^3/s are shown in bold.

		Acute Daily Maximum					**Chronic 7-day Daily Maximum**				
	Flow ($m^3 s$)	RD7	RD 6	RD 5	RD 4	RD 2	RD 7	RD 6	RD 5	RD 4	RD 2
Rainbow Trout	10	0	1	4	7	8	0	12	14	17	20
	20	0	0	3	6	7	0	9	14	17	20
	25	**0**	**0**	**2**	**5**	**7**	**0**	**7**	**14**	**17**	**20**
	30	0	0	2	4	7	0	4	14	17	20
	40	0	0	0	4	6	0	0	14	17	21
Brown Trout	10	0	0	2	4	4	0	2	10	14	15
	20	0	0	1	3	4	0	0	11	14	16
	25	**0**	**0**	**0**	**2**	**4**	**0**	**0**	**11**	**14**	**16**
	30	0	0	0	2	3	0	0	10	14	16
	40	0	0	0	1	3	0	0	8	14	16
Mountain Whitefish	10	0	8	11	12	15	0	16	18	20	27
	20	0	4	10	12	14	0	14	18	20	27
	25	**0**	**1**	**9**	**12**	**14**	**0**	**13**	**18**	**20**	**26**
	30	0	0	8	12	14	0	12	18	20	26
	40	0	0	7	11	13	0	9	17	20	26
Walleye / Sauger	10	0	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0	0
	25	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	30	0	0	0	0	0	0	0	0	0	0
	40	0	0	0	0	0	0	0	0	0	0

Table 4. Red Deer River IFN recommendations in AGRA (1995) and Grant (1974).

recommended minimum release from Dickson Dam:	Winter (Nov-Mar)	Spring (Apr-May)	Summer (Jun-Aug)	Fall (Sep-Oct)
	16	20-25	25-30	20-25

Table 5. Water quality IFN determinations (m^3s) for reaches of the Red Deer River, content adapted from Table 6.1 in Clipperton et al. (2003).

reach	Winter (wks 1-11, 51-52) (Dec17-Mar18)	Spring (wks 12-24) (Mar19-Jun17)	Summer (wks 25-37) (Jun18-Sep16)	Fall (wks 38-50) (Sep17-Dec16)
R7	16	16-23	18-33	17-22
R6	16	16-23	18-33	17-22
R5	16-17	17-23	17-33	17-21
R4	16-17	17-22	18-35	18-22
R3	16-18	17-23	22-40	18-25
R2	16-18	17-22	21-39	18-25
R1	16-18	17-22	21-39	18-25

2. IFN for Fish Habitat:

Fish habitat IFN determinations were based on 1) assessments of modeled habitat availability when site-specific data were available, and 2) the Tessmann method (1979) when site-specific data were unavailable (certain reaches and during the ice-covered period, weeks 1-13 and 45-52; November-March). Habitat-based IFN were set as the percent reductions to natural flows that were expected to result in only slight acute or slight chronic losses to available habitat. Alternatively, the Tessmann method was used to prescribe minimum monthly flows based on percent flow reductions to average annual or average monthly flows.

For habitat modeling, the habitat use of select sport fish species was considered in order to define required temporal and spatial distributions of habitat. Five sport fish species were used for the Red Deer River: brown trout (*Salmo trutta*), goldeye (*Hiodon alosoides*), lake sturgeon (*Acipenser fulvescens*), mountain whitefish (*Prosopium williamsoni*) and walleye (*Sander vitreus*), abbreviated as BNTR, GOLD, LKST, MNWH and WALL, respectively. The habitat use for each of their life-stages (fry, juvenile, adult, and spawning) were defined using Habitat Suitability Criteria (HSC) curves that were developed by a workshop of experts using site-specific data from across southern Alberta (Addley et al. 2003). HSC curves rate the suitability of habitat based on the flow-dynamic parameters of depth and velocity on a scale from 0 to 1 (0 being completely unsuitable and 1 being ideal—see Table 6). Substrate was included in the habitat assessments for spawning life-stages only, with 1 being assigned for small gravels to small cobbles and 0 otherwise (Addley et al. 2003; Clipperton et al. 2003).

The distribution of depths and velocities was modeled as a function of discharge using a one-dimensional Physical Habitat Simulation (PHABSIM) model (standard protocols: Bovee 1982, Milhous et al. 1989). Four segments of the Red Deer River were modeled with between four and six transects per segment (Golder 1999). These distributions were indexed to the habitat preferences (HSC data) for each species and life-stage. Suitable habitat was quantified in terms of weighted usable area (WUA; standardized from 0 to 1) to describe the proportion of suitable habitat relative to maximum habitat as a function of discharge. Habitat time-series were then produced by mapping weekly streamflow datasets with the WUA-discharge function to predict the quantity of suitable habitat for each species and life-stage in the modeled segments of the Red Deer River.

Naturalized weekly flow datasets were used for habitat time-series analyses. To preserve natural patterns of flow variability, a series of trial habitat time-series were constructed using a constant percent reduction from the naturalized weekly flows. The percent-reduction factor was repeated in a series of 5% increments (e.g. 5%, 10%, 15%...) to create a series of hypothetical flow and habitat time series. To prevent water withdrawals from occurring during naturally stressful low flow conditions, an Ecosystem Base Flow (EBF) threshold was set below which no water was withdrawn (i.e. natural flow is the IFN). Following Clipperton et al. (2002), the EBF was set weekly for each reach as the greater of the flow corresponding to either the 80% habitat exceedence for the species life-stage with the highest flow requirement, or the weekly 95% flow exceedence value.

To determine an IFN that would fully protect fish habitat, the trial 5% incremental habitat-time series were then compared to natural conditions using three metrics: loss in total average habitat, maximum weekly loss in average weekly habitat, and maximum instantaneous habitat loss. Based on values developed by Clipperton et al. (2002), critical thresholds for the respective metrics were set at 10% loss in total average habitat to prevent long-term chronic effects; 15% loss in weekly average habitat to prevent seasonal or shorter-term chronic effect; and 25% loss in weekly instantaneous habitat to prevent immediate acute effects. The fish habitat IFN determination was set to match the flow dataset having the greatest 5% incremental percent-flow reduction that did not exceed these critical thresholds.

The results for the metrics for each life-stage within its biologically significant period (BSP*) were reviewed for outliers and to determine if all metrics followed a consistent pattern of habitat loss. Based on this review, the final fish habitat IFN was either unadjusted or modified slightly to a different percent-flow reduction based on outliers and professional judgment. Each reach was evaluated on a species and life-stage basis. As a result, for the Red Deer River, the 20% and 25% incrementally-reduced flow datasets were selected as the IFN for fully protecting fish habitat.

Where modeling data were insufficient, monthly fish habitat IFN were set according to Tessmann's method (1979). Based on this method, if the average monthly flow is less than 40% of the annual average flow, then the monthly average flow is used as the IFN. Otherwise, the IFN is the greater of 40% of the monthly average flow, or 40% of the annual average flow. This prescription is described graphically in Figure 2.

* Biologically significant period (BSP) = A time period that has a common set of species life-stages present (Geer 1983). Species periodicity charts describing BSP's for the Red Deer River are presented in Figure 5.4 of Clipperton et al. 2003.

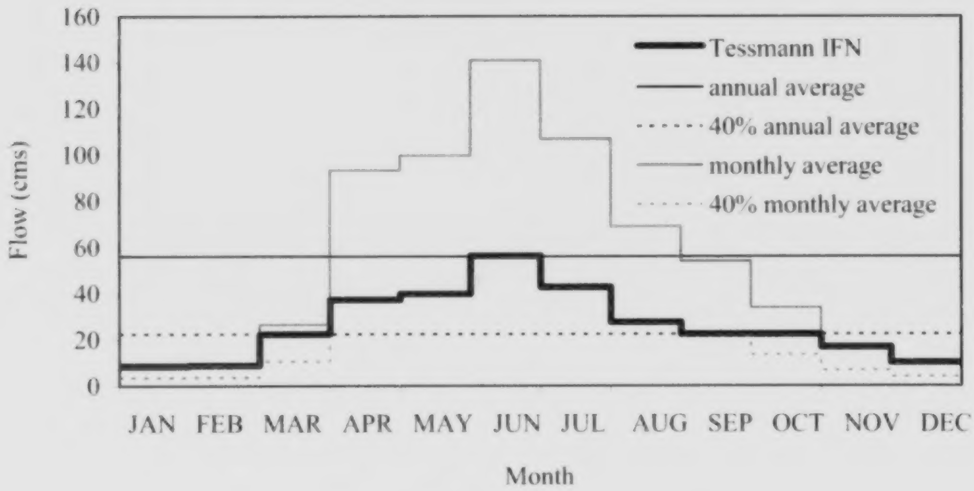

Figure 2. Graphic representation of Tessmann's method (1979) for setting monthly IFN (data shown are for reach 3 of the Red Deer River).

Table 6. Habitat Suitability Criteria values for the five sport fish species (BNTR = brown trout; GOLD = goldeye; LKST = lake sturgeon; MNWH = mountain whitefish; and WALL = walleye) in reaches of the Red Deer River (content adapted from Appendix A in Addley et al. 2003)

	Depth Suitability (DS) Criteria (D: depth is in m)								Velocity Suitability (VS) Criteria (V: velocity is in m/s)							
	Adult		Juvenile		Fry		Spawning / Eggs		Adult		Juvenile		Fry		Spawning / Eggs	
species	D	DS	D	DS	D	DS	D	DS	V	VS	V	VS	V	VS	V	VS
BNTR	0	0	0	0	0	0	0	0	0	1	0	0.8	0	1	0	0
	0.15	0	0.06	0	0.02	0	0.08	0	0.8	1	0.06	1	0.4	1	0.25	1
	0.6	1	0.4	1	0.08	1	0.15	1	1.1	0.2	0.8	1	0.6	0.3	0.75	1
	4	1	1.2	1	0.4	1	4	1	1.75	0	1.1	0.3	1	0	1.25	0
			1.6	0.2	1	0					1.45	0				
			4	0.2												
GOLD	0	0	0	0	0	0			0	1	0	1	0	1		
	0.3	0	0.25	0	0.02	0			0.6	1	0.55	1	0.05	0.1		
	0.8	0.2	0.7	0.1	0.45	1			0.9	0	0.85	0	0.2	0		
	1.5	1	1.4	1	0.75	1										
	4	1	2	1	1	0.4										
			2.5	0.3	2.5	0										
			4	0.3												
LKST	0	0					0	0	0	1	0	1	0	1	0	0
	0.5	0					0.5	0	0.8	1	0.2	1	0.05	1	0.1	0
	4	1					1	1	2	0	1	0	0.75	0	0.6	1
	10	1					10	1							0.85	1
	10	1													1.4	0.2
															1.5	0
MNWH	0	0	0	0	0	0	0	0	0	0.2	0	0.2	0	1	0	0
	0.15	0	0.06	0	0.01	0	0.15	0	0.4	1	0.35	1	0.7	1	0.15	0
	0.55	1	0.45	1	0.3	1	0.5	1	1	1	1.1	1	1	0.15	0.4	1
	4	1	1.4	1	1.15	1	4	1	1.2	0.4	1.8	0	1.25	0	1.1	1
			1.7	0.5	1.4	0.4			1.8	0					1.8	0
			4	0.5	1.8	0										
WALL	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0
	0.2	0	0.2	0	0.01	0	0.15	0	0.35	1	0.3	1	0.06	1	0.25	0
	0.5	0.2	1	1	0.3	1	0.7	1	0.5	0.5	0.9	0	0.25	0	0.5	1
	1	1	2.25	1	1.5	1	4	1	1	0					0.9	1
	4	1	2.7	0.2	2.1	0									1.1	0
			4	0.2												

3. IFN for Riparian Vegetation:

Riparian IFN were set at levels deemed sufficient to maintain natural patterns of survival, growth and succession in cottonwood forests. The IFN apply during the growing season (weeks 15-37; April 16 - September 16). Flow reductions were limited to levels associated with minimal effect, according to generally understood cottonwood lifecycle requirements and the extent of impact observed along test reaches in the SSRB. The IFN were defined by five exceedence and threshold-based requirements that set limits for weekly reductions to low, moderate and peak streamflow ranges, while providing a continuum of flows to help preserve ecosystem resiliency associated with natural flow variability. The development of these concepts is fully detailed by Gom (2002), Gom and Mahoney (2002), and Clipperton et al. (2003).

Scientifically reported flow requirements of cottonwoods were consulted in the development of the riparian IFN. Minimum flows for basic survival and maintenance are estimated to be about 40 to 60% of natural average weekly flow (Stromberg & Patten 1991) (note: 40% average weekly flow is approximately equivalent to 90% exceedence flow). Beyond minimum survival requirements, normal growth and development is thought to require natural annual average weekly flows (Stromberg & Patten 1990, 1996). Additionally, higher flows are important for seedling establishment. "Fringe" seedling recruitment has been associated with flood magnitudes of a five to 10-year return interval (RI)* (Mahoney & Rood 1998), and "general" recruitment tends to need higher flood magnitudes of about 30 to 50-year RI (Cordes et al. 1997, Hughes 1994, Rood & Mahoney 1991, Stromberg et al. 1993). Finally, natural frequencies of peak flood flows, ranging from bankfull to at least 125% bankfull, are thought to be critical for channel and floodplain processes that drive forest succession (Richter and Richter 2000).

These general, threshold-based requirements (shown as steps in Figure 3) were translated into a series of five weekly exceedence-based criteria to produce a variable flow recommendation. The criteria are that 1) there be no reductions to flows with natural exceedences of 90% or greater; 2) flows should not be reduced below the 90% exceedence level; 3) up to 35% reduction to natural flow is acceptable provided that 4) the natural RI is not increased more than 50%, and finally 5) the maximum IFN flow necessary is 125% bankfull. The decision process for meeting these five criteria is outlined in Figure 4, and an example exceedence curve for the resulting IFN is shown in Figure 3.

Each criterion influences a specific range of naturalized flow exceedences that correspond to population-level processes that affect the viability of riparian communities. The first and second criteria affect low flows with natural exceedences of about 100 to 90% and 90 to 60% respectively. Protection of these flow minima is required for basic cottonwood survival and forest maintenance. Criteria 3 and 4 influence moderate-range flows with natural exceedences of about 70 to 50% and 60 to 5%, respectively. These moderate flows are important for normal tree growth and development, and resulting

* RI (return interval) is the average length of time between two events of a given magnitude or greater. For example, a RI of 100 would describe a flow expected to occur on average once in every 100 years.

population maintenance. Finally, recommendation 5 defines maximum flows in the range of about 5% exceedence or less. These peak flows are associated with cottonwood seedling recruitment and ecological succession.

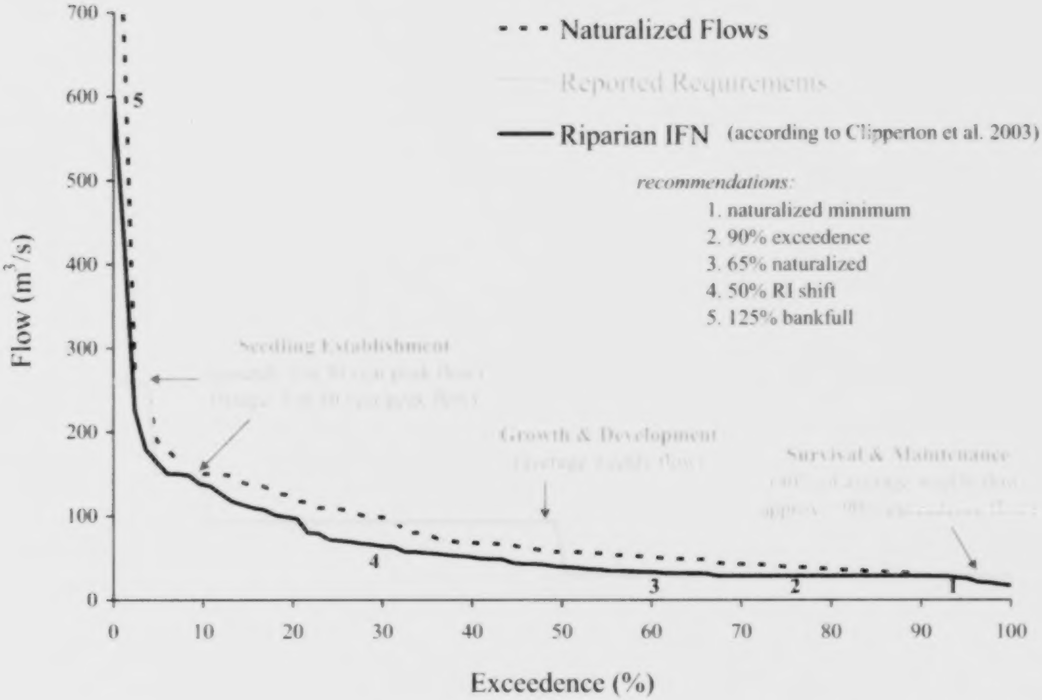

Figure 3. A weekly exceedence curve for riparian IFN flows (in blue) and general threshold-based flow requirements that have been reported for riparian cottonwoods. This example is from week 19 (May 17-24) on reach RD3 of the Red Deer River, and is based on naturalized flows for the 1912-1995 period.

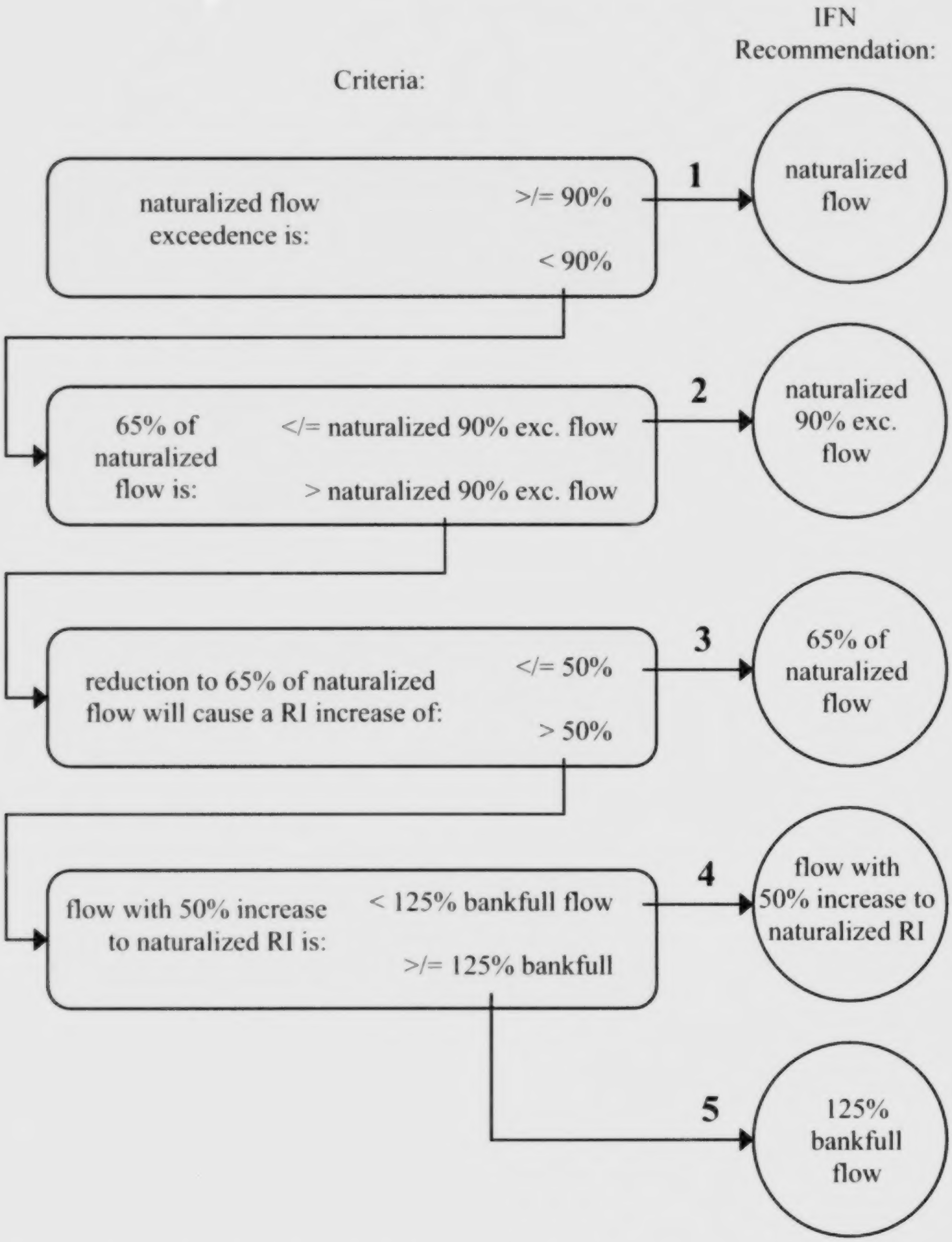

Figure 4. Decision chart for calculating weekly riparian IFN flows. The numbers correspond with the five IFN criteria.

4. IFN for Channel Maintenance:

The goal of IFN determinations for channel maintenance was to ensure that bed material would continue to be transported and that the physical characteristics of the channel would be maintained (e.g. riffles, pools, runs, point bars, etc.). Since detailed hydraulic data necessary to precisely model sediment transport was not available, an incipient-motion method based on the Shields entrainment function (Shields 1936) was used to define flows critical for bedload transport.

Based on hydraulic and sediment characteristics, the Shields number (S_N) was calculated using the formula described in Equation 1, for a range of flows for each reach. From the resulting discharge relationships (Figure 5), S_N values of 0.045 and 0.06 were used to define the flow ranges associated with effective initiation to general mobilization of bed materials. The resulting IFN recommendations (Table 7) were based on conserving the natural durations and frequencies of flows in these ranges.

Where data were insufficient to calculate the Shields number, the five-year return interval flow (the one in five year maximum flow) was used as an approximation of bankfull flow, which was expected to be capable of transporting the most sediment over time (discussed in Clipperton et al. 2003). The maximum flow requirement for channel maintenance was set at 125% of bankfull flow since this flow was expected to be sufficient to maintain overbank processes that include channel meandering (required by the riparian component). The Shields function provides a relatively coarse tool for setting IFN for channel maintenance, and more advanced tools should be investigated in future work.

Equation 1. Calculation of the Shields entrainment function (Shields 1936).

$$\mathbf{S_N = hS/((s-1)D)}$$

where:

S_N = Shields Number
h = mean depth of flow
S = hydraulic gradient *
s = dry density of bed sediment
D = median diameter of bed sediment

* *to compensate for resistance associated with river bends and channel irregularities, the effective slope (hydraulic gradient) was estimated as 85% of the channel slope.*

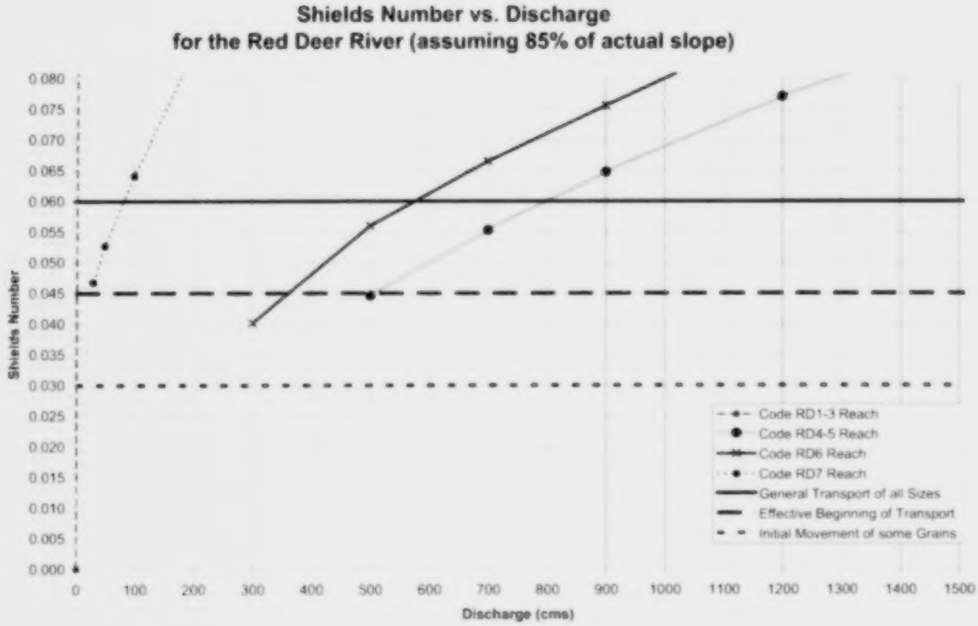

Figure 5. Relationship between discharge and the Shields number for reaches of the Red Deer River (revised Figure 8.2 from Clipperton et al. 2003).

Table 7. Recommended IFN ranges for channel maintenance that are needed for initiation of motion to fully developed in-depth bed movement, based on the Shield's Number (S_N) range of 0.045 – 0.060, for reaches of the Red Deer River.

Reach	(beginning of effective transport) S_N=0.045	(general transport) S_N=0.060
RD7	25 m^3/s	80 m^3/s
RD6	360 m^3/s	575 m^3/s
RD4-5	500 m^3/s	800 m^3/s
RD1-3	1 in 5 year max. flow = 679 m^3/s	

* *Note: these values differ from those reported in Table 8.1 of Clipperton et al. 2003, that inadvertently used 66% slope instead of 85% slope in calculating S_N for the Red Deer River.*

C. Integrated IFN for the Aquatic Ecosystem:

An integrated weekly IFN was produced by giving precedence to the individual IFN determination for the component with the highest flow requirement for a given flow exceedence. In this way, all lesser IFN flow requirements would also be met. To do this, the individual IFN for water quality, fish habitat, and riparian vegetation were calculated based on naturalized flows from 1912-1995, and formatted into weekly flow duration curves. For each week, the set of three curves was overlaid (e.g. Figure 6, bottom) and the maximum IFN values were used to produce an integrated IFN flow duration curve for that week (e.g. Figure 6, top). The weekly integrated IFN were subsequently evaluated and found to be adequate for channel maintenance relative to the Shields (1936) entrainment function.

In general, each ecosystem component defines flows of a particular magnitude and seasonality in the integrated IFN. Typically, seasonal flows in low, low-to-moderate, low-to-high, and peak ranges in the integrated IFN are determined by the water quality, fish habitat, riparian vegetation, and channel maintenance components respectively (as summarized in Table 8). The seasonality of each component is preserved as illustrated in Figure 7. As shown in these hydrographs, the integrated IFN is less than or equal to natural flow except for instances where water quality guidelines were imposed that required greater than natural flows to assimilate the waste load currently entering the river to acceptable levels (for the Red Deer River, this typically occurs in the winter, but can also occur in the summer during dry years).

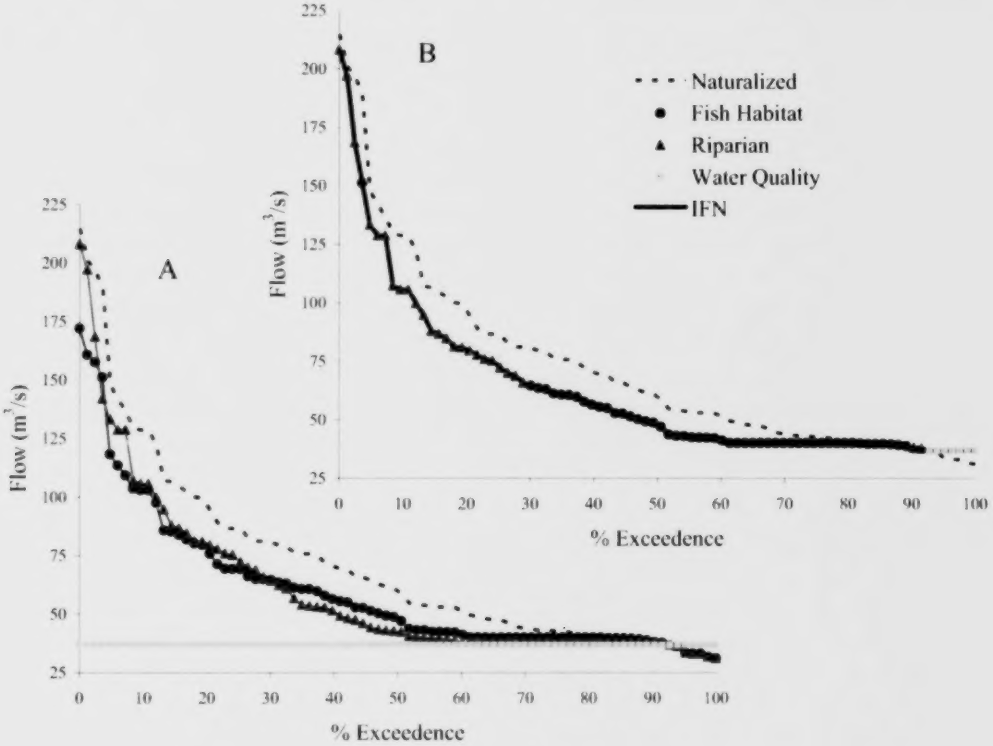

Figure 6. Example of flow duration curves for fish habitat, riparian, and water quality IFN components (A) and the integrated IFN (B) based on naturalized flows for week 32 (Aug 6-12) of the 1912-1995 period for Red Deer River Reach 3 (near Drumheller). The symbols shown in graph B indicate the component that defines the integrated IFN at each exceedence point.

Table 8. The format of each individual IFN and its contribution to the integrated ecosystem IFN.

Component:	IFN Format:	Flow range affected:	Period affected:
Water Quality	weekly single values	low	low flow periods (mainly in winter for the Red Deer River)
Fish Habitat	weekly duration curves	low to moderate	open water period (excluding spring freshet) & ice-covered period (winter)*
Riparian Vegetation	weekly duration curves	low to high	poplar growing season (spring & summer)
Channel Maintenance	annual threshold	high	period of annual flooding (spring)

** Flows for over-wintering habitat for fish during ice-covered periods were provided by Tessmann's method (1979).*

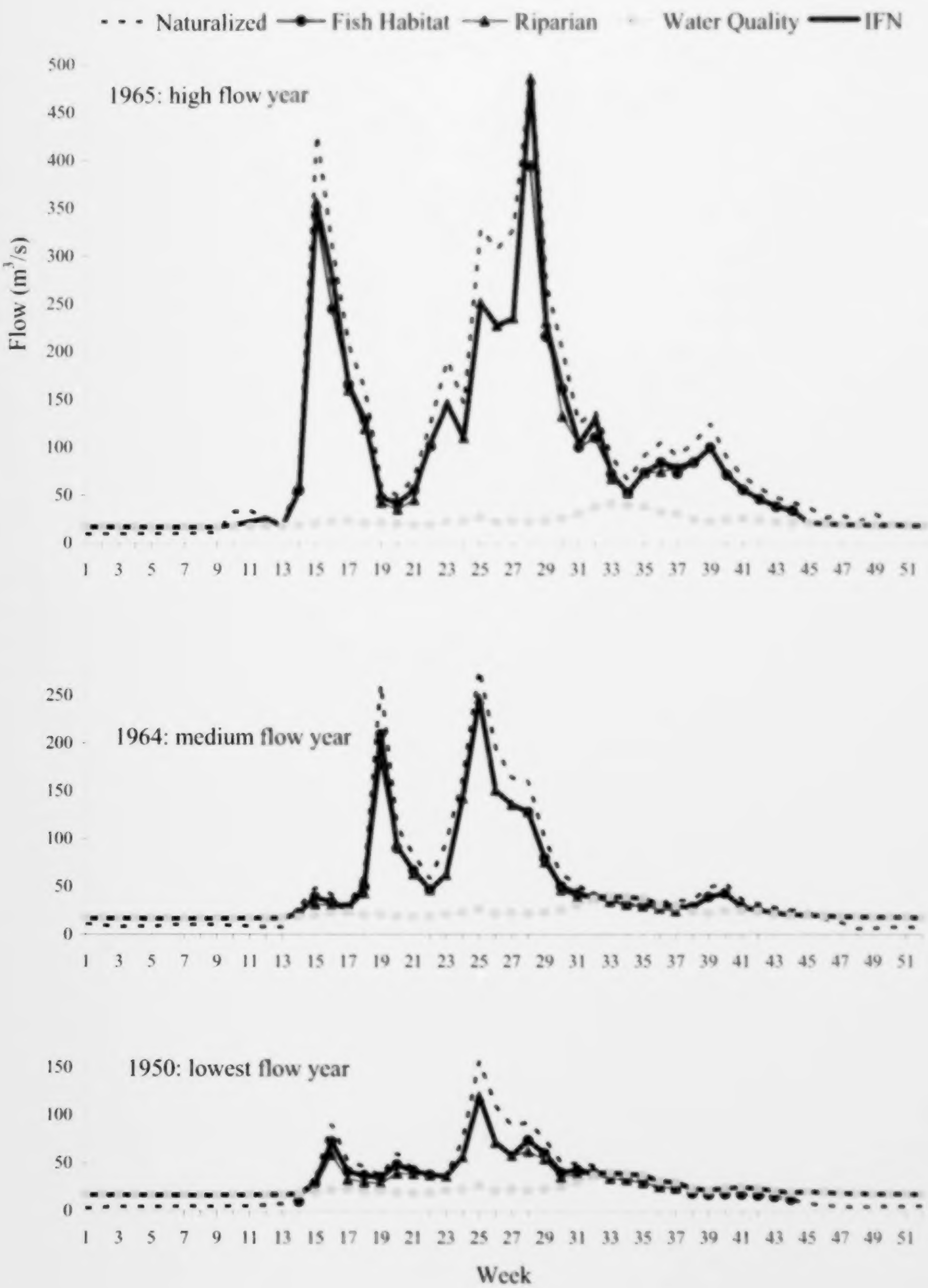

Figure 7. Example hydrographs of component and integrated IFN and naturalized flows from a high flow year (1965, top), a medium flow year (1964, middle) and a low flow year (1950, bottom) for Red Deer River Reach 3 (near Drumheller).

III - Impact Ratings

A. Background

Full protection to the aquatic environment was the objective for determining IFN in Clipperton et al. (2003). Because full protection may not be a mutually acceptable objective based on societal values or legal frameworks, water regulators are interested in understanding the ecosystem impacts of alternative water-use scenarios. There are two approaches to evaluating these scenarios. The first approach is to set ecosystem objectives prior to evaluating alternative flow scenarios, and then identify the scenario that most closely aligns with these objectives. The second approach is to create alternative water-use scenarios, assess their ecosystem impacts, and then identify whether the management benefits outweigh ecosystem costs. For the Red Deer River, the latter approach was adopted.

Two important limitations exist in assessing the impact of alternative flow scenarios on the ecosystem. First, there are many assumptions and uncertainties associated with the individual IFN determinations necessary to establish full protection (Clipperton et al. 2003). However, if we accept the natural flow paradigm as a premise, then errors will be minimized the closer IFN is to natural. When assessing alternative flow scenarios, there are no criteria for determining the specific impact of deviation from the IFN. Greater deviation in magnitude, duration, frequency, timing, or rate of change from the IFN can only be identified as having greater impact relative to the IFN itself.

Second, there is no easily and narrowly defined line or threshold at the transition between a healthy, functioning system and an unhealthy, degrading one. It is more reasonable to expect that a continuum of impacts would be associated with various degrees of flow modification. In general, the greater the deviation from a fully protective IFN, the more likely 1) change from natural will occur; 2) change will be more rapid, severe, and extensive; 3) recovery will take longer; and 4) changes may be irreversible. Furthermore, the continuum of impacts may be non-linear and disproportionately rapid changes can occur within narrow ranges of flow (thresholds).

Despite the above limitations, an ordinal scale of ecosystem impact was developed for the Red Deer River and a number of alternative flow scenarios were evaluated. The ordinal scale consisted of four categories: slight, marginal, serious and extreme. The categories were based on similar efforts carried out in North America and further abroad. On the Upper Mississippi, a similar four-category scale was classified as unchanged, moderately impacted, heavily impacted and degraded (U.S. Geological Survey 1999). In Australia, a three-category scale has been used: no to minor impacts, moderate impacts, and major to very major impacts (Brizga et al. 2001). In South Africa, a six-category scale in terms of severity of change has been used: none, negligible, low, moderate, severe, critically severe (Brown and King 2002). Recently, Alberta Environment completed an aquatic ecosystem health information synthesis and initial assessment of 11 major rivers with multiple reaches and 14 tributaries to these major rivers. The following information was used to carry out the assessment: water quality, sediment quality and non-fish biota

(benthic invertebrates and primary producers). A five-category scale was adopted: excellent, good, fair, marginal and poor (North/South Consultants Inc., Clearwater Consultants Inc. and Patricia Mitchell Environmental Consulting 2007).

The following flow scenarios were evaluated for the Red Deer River:

1) **Natural Flow** – This is the pattern of flow that would have occurred between 1912 and 1995 along the Red Deer River without any water diversions, dams or other human interventions. These are modeled flows and are referred to as naturalized flows. The natural flow regime will support the natural diversity and dynamics of the riverine ecosystem indefinitely. It therefore provides a baseline against which to compare alterations to flow.

2) **Present Use of Existing Licenses** – This is the pattern of flow in the Red Deer River during the last 25 years since operation of the Dickson Dam. These are flows that have largely contributed to the current condition of the riverine ecosystem. There are licensed water allocations not presently used to their full extent. As these allocations are used more completely in the future, the riverine ecosystem will continue to change. Even though the Red Deer River is not highly allocated at present, existing flows are often quite different from natural flows. This is due to flow reduction in the spring and augmented flows for much of the winter.

3) **Instream Flow Need** – This is the pattern of river flow that has been scientifically determined (Clipperton et al., 2003) to sustain a substantially natural aquatic ecosystem over the long term. Limitations to providing these flows such as existing allocations and water law are not considered. For the Red Deer River, an additional demand is included in the IFN determination. To assimilate the waste load currently entering the river to target levels, minimum winter flows are increased over the natural level to 16 cubic meters per second.

4) **Increased Use of Existing Licenses** - This scenario is the predicted outcome of all existing allocations and other commitments throughout the South Saskatchewan River Basin being used to their fullest practical extent in the future. It uses existing instream objectives in the Red Deer River of 8.5 cubic meters per second for irrigation licenses and 4.25 cubic meters per second for non-irrigation licenses. It does not include any other proposed allocation increases such as Special Areas Water Supply Project (SAWSP) within the Red Deer River Basin.

5) **New Licenses with High WCO** - This scenario is the predicted outcome if new licenses were limited to 600,000 dam^3 and IFN was used as the water conservation objective (WCO) for new licenses within the Red Deer River Basin. Allocations include SAWSP, the Acadia Valley irrigation project, and non-irrigation demand for the medium projection to 2046. The WCO would rarely be met as existing licenses are not subject to this restriction. The water supply for future allocations (including those listed above) would be very limited due to the high WCO.

6) **New Licenses with Proposed WCO** – This scenario is the predicted outcome of the WCO recommended in the draft water management plan and an allocation limit of 600,000 dam^3 applied to new licenses for the Red Deer River. Allocations include SAWSP, Acadia Valley irrigation project, and non-irrigation demand for the medium projection to 2046. The recommended WCO frequently would not be met as existing licenses are not subject to this restriction. Future allocations would be possible, but most licenses, particularly those for year round water use, would require storage.

B. Impact Ratings for Ecosystem Components:

1. Impact Ratings for Water Quality:

In order to rate the impact of the alternative flow scenarios, the water quality results from three existing CE-QUAL-W2 modeling runs (present use, 50% IFN as WCO, and 45% of natural flow) were consulted in producing a relative ranking based on professional judgment that assigned level of impact among four general categories (Table 9). In addition to water temperature, the water quality constituents that were simulated included: total dissolved solids, bacteria, phosphorous, ammonium, nitrate-nitrite, dissolved and particulate organic matter, CBOD (Carbonaceous Biochemical Oxygen Demand), algae, epiphyton, and dissolved oxygen (DO). Dissolved oxygen was chosen as the key parameter in this rating scheme since it has widespread effects and is sensitive to flow modifications. Based on the DO guidelines for protecting local fish species (discussed in section II.B.1 and summarized in Table 2), guideline exceedences for the DO results from the three modeling runs (Table 10) were analyzed. Based on these data and trends in the other water quality constituents, a relative impact rating was developed (Table 11).

In summary, natural flows were assessed as a hypothetical benchmark that was expected to have the least impact on water quality. It was given a "slight" impact rating with the understanding that natural flows would be inadequate to handle current human loadings that are beyond levels associated with natural conditions. The IFN were assessed as a second benchmark since they were designed to meet minimum WQ guidelines. As such, these flows were given a "slight" impact rating, and were expected to define the hypothetical junction between the slight and marginal impact categories. The remaining four flow scenarios were then ranked relative to these benchmarks. Since the WQ guideline exceedences for the "Present Use of Existing Licenses" scenario were similar to those for the IFN, they were also given the "slight" impact rating. Although model results were not directly available for "Increased Use of Existing Licenses," this scenario was expected to resemble "Present Use," and so was also given a "slight" rating. The impact ratings for "New Licenses with High WCO" and "New Licenses with Proposed WCO," were based on assessments of existing modeling runs for the "50% IFN WCO" and "45% of natural flow" scenarios, respectively. Both scenarios were rated in the "marginal" impact category since in the lower reaches of the Red Deer River, the WQ guideline exceedences are beyond the benchmark provided by the IFN (Table 10).

Table 9: Impact categories for water quality (note: this is not necessarily a linear scale)

Impact Categories:	slight	marginal	serious	Extreme
Guidelines:	Water quality guidelines mostly met	Some guidelines exceeded. Exceedences increasing in frequency and magnitude		Many guidelines exceeded
Conditions:	Natural	Progressively deteriorating (slightly, measurable to significant)		Toxic conditions for aquatic biota

Summary of WQ impacts:

Waste assimilation	Sufficient	Insufficient		Appreciable waste accumulations
Excess weeds and algae	Limited	Increasing accumulations with negative impacts on WQ		Weeds and algae impeding river flows
Toxic substances and other [illegible]	Healthy	Increasingly unhealthy; loss of biodiversity ([illegible])		Toxic, lethal conditions for key species (ecosystem collapse)

Table 9. Impact categories for water quality (note: this is not necessarily a linear scale)

Impact Categories:	**slight**	marginal	serious	Extreme
Guidelines:	Water quality guidelines mainly met	Some guidelines exceeded. Exceedences increasing in frequency and magnitude		Many guidelines exceeded
Conditions:	Natural	Progressively deteriorating *(slightly measurable to significant)*		Toxic conditions for aquatic biota
Summary of WQ impacts:				
Waste assimilation	Sufficient	Insufficient		Appreciable waste accumulations
Aquatic weeds and algae	Limited	Increasing accumulation *(compounding worsening WQ)*		Weeds and algae impeding river flows
Fish communities and other aquatic organisms	Healthy	Increasingly unhealthy; loss of biodiversity *(DO levels and temperatures)*		Toxic / lethal conditions for key species *(ecosystem collapse)*

Table 10. Modeled dissolved oxygen guideline exceedences.

		chronic guideline			acute guideline		
		Duration of 7-day average < 6.5 mg/L (days)	Period that guideline is exceeded (days)		Duration of 1-day average < 5.0 mg/L (days)	Period that guideline is exceeded (days)	
Present Use (similar to IFN)							
RD6	Red Deer	0	-	-	0	-	-
RD5	Nevis	0	-	-	0	-	-
RD4	Morrin Bridge	0	-	-	0	-	-
RD3, RD2	Jenner	56	Dec 5	Feb 14	0	-	-
RD1	Bindloss	77	Dec 3	Feb 24	22	Dec 30	Feb 7
New Licenses with High WCO (surrogate scenario used = 50% IFN as WCO)							
RD6	Red Deer	0	-	-	0	-	-
RD5	Nevis	0	-	-	0	-	-
RD4	Morrin Bridge	0	-	-	0	-	-
RD3, RD2	Jenner	69	Dec 2	Feb 14	0	-	-
RD1	Bindloss	80	Dec 1	Feb 19	57	Dec 1	Feb 7
New Licenses with Proposed WCO (surrogate scenario used = 45% of natural flow)							
RD6	Red Deer	0	-	-	0	-	-
RD5	Nevis	0	-	-	0	-	-
RD4	Morrin Bridge	0	-	-	0	-	-
RD3, RD2	Jenner	71	Dec 2	Feb 16	2	Jan 31	Feb 3
RD1	Bindloss	80	Dec 1	Feb 19	61	Nov30	Feb 7

Table 11. Water quality impact ratings of six alternative flow scenarios for the Red Deer River

Scenario	Impact
1) Natural Flow	**Slight**
Flows provide naturally occurring levels of water quality. Desired levels of water quality may not be met due to current loadings.	
2) Present Use of Existing Licenses	**Slight**
Most water quality guidelines met through water management. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	
3) Instream Flow Need	**Slight**
Most water quality guidelines met. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	
4) Increased Use of Existing Licenses	**Slight**
Estimate. Most water quality guidelines met. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	
5) New Licenses with High WCO	**Marginal**
Estimate: significant increase in duration and extent of dissolved oxygen guideline exceedences in lower reaches in winter months. Potential for temperature guideline exceedences in fall and ammonia exceedences in spring. Potential for increased aquatic weed growth.	
6) New Licenses with Proposed WCO	**Marginal**
Significant increase in duration and extent of dissolved oxygen guideline exceedences in lower reaches in winter months. Potential for temperature guideline exceedences in fall and ammonia exceedences in spring. Potential for increased aquatic weed growth.	

2. Impact Ratings for Fish Habitat

Overview

Since a suite of tools was not available to demonstrate a direct relationship between flow and a measure of fish health (such as a population growth index), a subjective method for rating the impact of alternative flow scenarios on fish was developed based on differences in the modeled availability of suitable fish habitat. The approach evaluated habitat loss using the same three metrics used in determining IFN for the protection of fish habitat (Clipperton et al. 2003), together with tallies of the numbers of negatively impacted fish species / life stages. Based on a subjective assessment of this information, the impacts of alternative scenarios were ranked and assigned to one of four impact categories (Table 12). Natural flows and IFN recommendations served as benchmarks to define habitat loss associated with the "slight" impact category: natural flows were expected to have no impact, and IFN flows were expected to have negligible impact. Beyond the "slight" category, the level of impact was estimated based on professional judgment since no other benchmarks were available.

Table 12. Impact categories for fish habitat.

	slight	marginal	serious	extreme
Impacts on Fish:	Natural population structure, function, and taxonomic integrity maintained	Progressive deterioration (slightly measurable to significant) in the structure and function of populations and health of individuals *note: this is not a linear scale since thresholds likely exist*		System collapse, extirpation of populations

Specifics

Time-series were conducted for each alternative flow scenario in order to model the availability of habitat for each resident fish species and life-stage (methodologies are detailed in section II.B.2 of this report). Values for the three fish metrics – 1) loss in total average habitat, 2) maximum weekly loss in average habitat, and 3) maximum instantaneous habitat loss – were calculated for each scenario. The thresholds between slight and marginal impact, associated with these three metrics were 10%, 15%, and 25%, respectively (to prevent long-term chronic effects, seasonal or short-term chronic effects, and immediate acute effects, respectively). The raw values for each of the three metrics are summarized in Table 13a, b, and c.

To assist qualitative assessment, the data were summarized as follows. Average values for each metric were calculated for each scenario across the life-stages occurring in each reach (note: fry life-stages were omitted for metrics 1 and 2) (Table 14). While all of the

Table 11. Water quality impact ratings of six alternative flow scenarios for the Red Deer River.

Scenario	Impact
1) Natural Flow	
Flows provide naturally occurring levels of water quality. Desired levels of water quality may not be met due to current loadings.	
2) Present Use of Existing Licenses	**Slight**
Most water quality guidelines met through water management. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	
3) Instream Flow Need	**Slight**
Most water quality guidelines met. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	
4) Increased Use of Existing Licenses	**Slight**
Estimate: Most water quality guidelines met. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	
5) New Licenses with High WCO	**Marginal**
Estimate: significant increase in duration and extent of dissolved oxygen guideline exceedences in lower reaches in winter months. Potential for temperature guideline exceedences in fall and ammonia exceedences in spring. Potential for increased aquatic weed growth.	
6) New Licenses with Proposed WCO	**Marginal**
Significant increase in duration and extent of dissolved oxygen guideline exceedences in lower reaches in winter months. Potential for temperature guideline exceedences in fall and ammonia exceedences in spring. Potential for increased aquatic weed growth.	

2. Impact Ratings for Fish Habitat:

Overview:

Since a suite of tools was not available to demonstrate a direct relationship between flow and a measure of fish health (such as a population growth index), a subjective method for rating the impact of alternative flow scenarios on fish was developed based on differences in the modeled availability of suitable fish habitat. The approach evaluated habitat loss using the same three metrics used in determining IFN for the protection of fish habitat (Clipperton et al. 2003), together with tallies of the numbers of negatively impacted fish species' life-stages. Based on a subjective assessment of this information, the impacts of alternative scenarios were ranked and assigned to one of four impact categories (Table 12). Natural flows and IFN recommendations served as benchmarks to define habitat loss associated with the "slight" impact category; natural flows were expected to have no impact, and IFN flows were expected to have negligible impact. Beyond the "slight" category, the level of impact was estimated based on professional judgment since no other benchmarks were available.

Table 12. Impact categories for fish habitat.

	slight	marginal	[illegible]	extreme
Impacts on Fish:	Natural population structure, function, and taxonomic integrity is maintained	Progressive deterioration (slightly measurable to significant) in the structure and function of populations and health of individuals *note: this is not a linear scale since thresholds likely exist*		System collapse; extirpation of populations

Specifics:

Time series were conducted for each alternative flow scenario in order to model the availability of habitat for each resident fish species and life-stage (methodologies are detailed in section II.B.2 of this report). Values for the three fish metrics—1) loss in total average habitat; 2) maximum weekly loss in average habitat; and 3) maximum instantaneous habitat loss—were calculated for each scenario. The thresholds between slight and marginal impact, associated with these three metrics were 10%, 15%, and 25%, respectively (to prevent long-term chronic effects, seasonal or short-term chronic effects, and immediate acute effects, respectively). The raw values for each of the three metrics are summarized in Table 13a, b, and c.

To assist qualitative assessment, the data were summarized as follows. Average values for each metric were calculated for each scenario across the life-stages occurring in each reach (note: fry life-stages were omitted for metrics 1 and 2) (Table 14). While all of the

reaches were considered, Reach 3 was the primary reach selected for assessment since it had the greatest separation in the values of the metrics for the most life-stages. The numbers of life-stages adversely affected beyond the critical threshold for each metric were also considered for each flow scenario (Table 15). Based on these summary statistics, the "Present Use of Existing Licenses" scenario was found to be very similar to the IFN recommendation, and was ranked in the "slight" impact category. The other three management scenarios ("Increased Use of Existing Licenses," "New Licenses with High WCO," and "New Licenses with Proposed WCO") had up to a 92% loss in habitat for individual species and life stages; up to a 62% loss in habitat averaged across species; and up to 100% of the species and life history stages having moderate or greater impacts to their habitat. Although the exact implications of these levels of habitat reduction are unknown, it was assumed there would be serious impacts to all fish populations. Thus, these scenarios were ranked in the "serious" impact category. The impact category and description of the rating for each scenario are summarized in Table 16.

Table 13a. Value for each metric for the "Present Use" flow scenario and Fish IFN for the period 1984-2001. Grey cells indicate where species/life-stages do not naturally occur. Black cells indicate that the slight/marginal threshold for that metric is exceeded. Values in brackets indicate the proportion of weeks where the slight/marginal threshold was exceeded (absence = 0%).

		2) Present Use of Existing Licenses			3) Fish IFN		
		RD6	RD3	RD1	RD6	RD3	RD1
Metric 1: Overall Habitat Reduction (%) (threshold = -10)							
BNTR	adult	-1			0		
	juvenile	0			1		
	spawning						
GOLD	adult		-3	3		-7	-7
	juvenile		-3	2		-5	-5
	fry		2	-4		8	9
MNWH	adult	-3			-4		
	juvenile	-2			-2		
	spawning	-3			-13		
WALL	adult	3	-2	2	8	-3	-2
	juvenile	2	-1	1	7	0	0
	fry		-2	2		-4	-4
	spawning		--	--		--	--
LKST	adult		-5	4		-15	-15
Metric 2: Maximum Weekly Reduction (%) (threshold = -15)							
BNTR	adult	-4			-4		
	juvenile	-3			-3		
	spawning						
GOLD	adult		-10	-5		-13	-12
	juvenile		-9	-3		-10	-10
	fry		-2	-8		-1	4
MNWH	adult	-9			-10		
	juvenile	-6			-7		
	spawning	-9			-16 (29%)		
WALL	adult	-2	-6	-2	-3	-7	-7
	juvenile	-1	-5	-2	-2	-4	-5
	fry		-3	0		-8	-4
	spawning		-20 (14%)	-9		-19 (36%)	-18 (18%)
LKST	adult		-16 (7%)	-7		-21 (53%)	-21 (57%)
Metric 3: Maximum Instantaneous Reduction (%) (threshold = -25)							
BNTR	adult	-35 (1%)			-13		
	juvenile	-27 (<1%)			-8		
	spawning						
GOLD	adult		-66 (4%)	-45 (2%)		-31 (1%)	-30 (2%)
	juvenile		-59 (5%)	-42 (1%)		-23	-23
	fry		-37	-63 (1%)		-27	-29 (<1%)
MNWH	adult	-57 (4%)			-21		
	juvenile	-50 (2%)			-16		
	spawning	-39 (1%)			-29 (2%)		
WALL	adult	-46 (1%)	-45 (2%)	-27 (<1%)	-12	-13	-16
	juvenile	-59 (1%)	-41 (1%)	-19	-9	-11	-11
	fry		-25	-11		-47	-12
	spawning		-79 (4%)	-56 (2%)		-41 (3%)	-42 (3%)
LKST	adult		-77 (11%)	-58 (4%)		-36 (7%)	-37 (10%)

Note that, although the data are not presented here, the metric values for the natural flow scenario are all zero.

Table 13b. Value for each metric for Fish IFN and "Increased Use of Existing Licenses" flow scenario for the period 1928-1995. Grey cells indicate where species/life-stages do not naturally occur. Black cells indicate that the slight/marginal threshold is exceeded. Values in brackets indicate the proportion of weeks where the slight/marginal threshold was exceeded (absence = 0%).

Metric 1: Overall Habitat Reduction (%) (threshold = -10)

		3) Fish IFN				4) Increased Use of Existing Licenses			
		RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3
BNTR	adult	-2	-2			-1	-2		
	juvenile	-4	-1			-2	-1		
	spawning	-1				0			
GOLD	adult			-4	-7			-5	-16
	juvenile			-2	-5			-4	-13
	fry				7				4
MNWH	adult	-3	-6			-2	-5		
	juvenile	-5	-4			-3	-4		
	spawning	-5	-15			0	-7		
WALL	adult	0	3	4	-3	1	1	2	-10
	juvenile		3	2	-1		1	0	-8
	fry			16	-2			19	0
	spawning			4	-11			-8	-24
LKST	adult				-15				-21

Metric 2: Maximum Weekly Reduction (%) (threshold = -15)

		3) Fish IFN				4) Increased Use of Existing Licenses			
		RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3
BNTR	adult	-8	-5			-4	-5		
	juvenile	-7	-4			-7	-3		
	spawning	-2				0			
GOLD	adult			-6	-11			-8	-25 (50%)
	juvenile			-5	-9			-7	-22 (43%)
	fry				2				1
MNWH	adult	-8	-10			-8	-9		
	juvenile	-8	-9			-8	-7		
	spawning	-7	-20 (43%)			-2	-10		
WALL	adult	-12	-7	-1	-7	-5	-3	-1	-17 (13%)
	juvenile		-5	-1	-7		-3	-2	-15 (3%)
	fry			-3	-3			-8	-1
	spawning			-9	-17 (23%)			-17 (15%)	-34 (77%)
LKST	adult				-18 (53%)				-32 (70%)

Metric 3: Maximum Instantaneous Reduction (%) (threshold = -25)

		3) Fish IFN				4) Increased Use of Existing Licenses			
		RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3
BNTR	adult	-20	-7			-28	-38		
	juvenile	-21	-7			-35 (1%)	-25		
	spawning	-8				-4			
GOLD	adult			-11	-22			-43 (2%)	-76 (33%)
	juvenile			-9	-17			-44 (1%)	-70 (27%)
	fry				-31				-21
MNWH	adult	-17	-15			-28	-65 (3%)		
	juvenile	-14	-14			-40 (2%)	-56 (2%)		
	spawning	-14	-31 (10%)			-16	-38 (2%)		
WALL	adult	-27 (3%)	-14	-18	-12	-37 (1%)	-50 (1%)	-39	-56 (14%)
	juvenile		-11	-15	-11		-57 (1%)	-42	-53 (11%)
	fry			-28 (2%)	-7			-40 (1%)	-38
	spawning			-33 (3%)	-23			-89 (21%)	-92 (60%)
LKST	adult				-24				-85 (46%)

Table 13c. Value for each metric for Fish IFN and "New Licenses with High WCO" and "New Licenses with Proposed WCO" flow scenarios for the period 1928-1995. Grey cells indicate where species/life-stages do not naturally occur. Black cells indicate that the slight/marginal threshold is exceeded. Values in brackets indicate the proportion of weeks where the slight/marginal threshold was exceeded.

Metric 1: Overall Habitat Reduction (%) (threshold = -10)

		3) Fish IFN				5) New Licenses with High WCO				6) New Licenses with Proposed WCO			
		RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3
BNTR	adult	-2	-2			0	-1			-1	-2		
	juvenile	-4	-1			-1	-1			-2	-2		
	spawning	-1				0				0			
GOLD	adult			-4	-7			-5	-14			-5	-21
	juvenile			-2	-5			-4	-12			-4	-18
	fry				7				6				5
MNWH	adult	-3	-6			0	-3			-2	-4		
	juvenile	-5	-4			-1	-2			-3	-4		
	spawning	-5	-15			-2	-9			-1	-7		
WALL	adult	0	3	4	-3	0	1	2	-9	1	-2	2	-14
	juvenile		3	2	-1		1	0	-7		-1	1	-11
	fry			16	-2			19	-1			20	2
	spawning			4	-11			-4	-21			-6	-31
LKST	adult				-15				-20				-28

Metric 2: Maximum Weekly Reduction (%) (threshold = -15)

		3) Fish IFN				5) New Licenses with High WCO				6) New Licenses with Proposed WCO			
		RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3
BNTR	adult	-8	-5			-9	-6			-6	-4		
	juvenile	-7	-4			-12	-4			-7	-3		
	spawning	-2				0				0			
GOLD	adult			-6	-11			-8	-27 (47%)			-9	-30 (77%)
	juvenile			-5	-9			-7	-24 (33%)			-7	-27 (60%)
	fry				2				1				-1
MNWH	adult	-8	-10			-9	-12			-7	-8		
	juvenile	-8	-9			-13	-9			-9	-6		
	spawning	-7	-20 (43%)			-4	-14			-2	-10		
WALL	adult	-12	-7	-1	-7	-10	-4	-1	-18 (17%)	-7	-3	-1	-20 (40%)
	juvenile		-5	-1	-7		-3	-2	-16 (7%)		-3	-2	-20 (30%)
	fry			-3	-3			-15 (3%)	-3			-9	-1
	spawning			-9	-17 (23%)			-18 (8%)	-37 (77%)			-11	-41 (67%)
LKST	adult				-18 (53%)				-35 (87%)				-38 (97%)

Metric 3: Maximum Instantaneous Reduction (%) (threshold = -25)

		3) Fish IFN				5) New Licenses with High WCO				6) New Licenses with Proposed WCO			
		RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3
BNTR	adult	-20	-7			-32	-37 (1%)			-32	-29		
	juvenile	-21	-7			-32	-28			-32	-24		
	spawning	-8				-5				-4			
GOLD	adult			-11	-22			-39 (3%)	-76 (27%)			-39 (1%)	-75 (52%)
	juvenile			-9	-17			-35 (1%)	-71 (22%)			-35 (1%)	-69 (44%)
	fry				-31				-23				-21
MNWH	adult	-17	-15			-27	-59 (5%)			-24	-49 (3%)		
	juvenile	-14	-14			-32 (2%)	-51 (4%)			-31 (1%)	-45 (2%)		
	spawning	-14	-31 (10%)			-9	-36 (5%)			-12	-36 (4%)		
WALL	adult	-27 (3%)	-14	-18	-12	-37 (3%)	-43 (1%)	-17	-57 (13%)	-38 (3%)	-43 (1%)	-19	-56 (25%)
	juvenile		-11	-15	-11		-35	-15	-56 (11%)		-38	-22	-55 (20%)
	fry			-28 (2%)	-7			-53 (1%)	-38			-45 (1%)	-38
	spawning			-33 (3%)	-23			-86 (16%)	-92 (51%)			-86 (7%)	-91 (52%)
LKST	adult				-24				-83 (42%)				-82 (68%)

Table 14. Averages of metric values across life-stages occurring in each reach (note: fry life-stages were omitted from the average for metrics 1 and 2).

reach		2) Present Use	(1984-2001) 3) Fish IFN	(1928-1995) 3) Fish IFN	4) Increased Use	5) High WCO	6) Proposed WCO
RD1	Metric 1	2.4	-5.8				
	Metric 2	-4.7	-12.2				
	Metric 3	-40.1	-25.0				
RD3	Metric 1	-2.8	-6.0	-7.0	-15.3	-13.8	-20.5
	Metric 2	-11.0	-12.3	-11.5	-24.2	-26.2	-29.3
	Metric 3	-53.6	-28.6	-18.4	-61.4	-62.0	-60.9
RD5	Metric 1			0.8	-3.0	-2.2	-2.4
	Metric 2			-4.4	-7.0	-7.2	-6.0
	Metric 3			-19.0	-49.5	-40.8	-41.0
RD6	Metric 1	-0.6	-0.4	-3.1	-2.4	-2.0	-3.1
	Metric 2	-4.9	-6.4	-8.6	-5.7	-7.4	-5.3
	Metric 3	-44.7	-15.4	-14.1	-47.0	-41.3	-37.7
RD7	Metric 1			-2.5	-0.9	-0.5	-1.0
	Metric 2			-6.5	-4.3	-7.1	-4.8
	Metric 3			-15.1	-23.5	-21.8	-21.6

Table 15. Number of life-stages present along each reach and proportion that would be adversely affected beyond the slight/marginal threshold for each metric, for each flow scenario.

Life-stages	2) Present Use			(1984-2001) 3) Fish IFN			(1928-1995) 3) Fish IFN				4) Increased Use				5) High WCO				6) Proposed WCO			
	RD6	RD3	RD1	RD6	RD3	RD1	RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3	RD7	RD6	RD5	RD3
total present:	7	8	8	7	8	8	7	7	6	8	7	7	6	8	7	7	6	8	7	7	6	8
% impacted:																						
Metric 1	0	0	0	14.3	12.5	12.5	0	14.3	0	25	0	0	0	50	0	0	0	50	0	0	0	75
Metric 2	0	25	0	14.3	25	25	0	14.3	0	25	0	0	16.7	62.5	0	0	16.7	75	0	0	0	75
Metric 3	100	87.5	75	14.3	62.5	50	14.3	14.3	33.3	12.5	71.4	85.7	100	87.5	71.4	100	66.7	87.5	57.1	85.7	66.7	87.5

Table 10. Fish habitat impact ratings of six alternative flow scenarios for the Red Deer River.

Scenario	Impact
1) Natural Flow	**Slight**
Fish populations are at natural levels. Natural population structure, function, and taxonomic integrity preserved.	
2) Present Use of Existing Licenses	**Slight**
Undetectable changes to population structure and function. Similar to natural community. Fish populations are fully maintained.	
3) Instream Flow Need	**Slight**
Barely detectable changes to structure and function of the natural population expected. Fish populations are intact and healthy.	
4) Increased Use of Existing Licenses	**Serious**
Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	
5) New Licenses with High WCO	**Serious**
Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	
6) New Licenses with Proposed WCO	**Serious**
Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	

Table 16. Fish habitat impact ratings of six alternative flow scenarios for the Red Deer River

Scenario	Impact
1) Natural Flow	[redacted]
Fish populations are at natural levels. Natural population structure, function, and taxonomic integrity preserved.	
2) Present Use of Existing Licenses	[redacted]
Undetectable changes to population structure and function. Similar to natural community. Fish populations are fully maintained	
3) Instream Flow Need	**Slight**
Barely detectable changes to structure and function of the natural population expected. Fish populations are intact and healthy.	
4) Increased Use of Existing Licenses	[redacted]
Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	
5) New Licenses with High WCO	[redacted]
Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	
6) New Licenses with Proposed WCO	[redacted]
Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	

3. Impact ratings for Riparian Vegetation:

The impact of alternative flow scenarios on riparian vegetation was evaluated using a ratings method based on five metrics—one for each of the five decision criteria used to determine riparian IFN (Figure 4). The value for each metric was calculated based on the exceedence range of the flows affected; flows with exceedence ranges of 100 to 90%, 60 to 90%, 50 to 70%, 5 to 60%, and those with less than 5% exceedence were used in calculating values for metrics 1 through 5 respectively. Metric 1 summarized the percent change from naturalized flows. Metric 2 summarized flows as a percent of the naturalized 90% exceedence flow. Metric 3 summarized percent changes from naturalized flows. Metric 4 summarized return-interval shifts as a percent of the return-interval for naturalized flows. Metric 5 summarized the percent change to the natural occurrence of weekly flows greater than or equivalent to bankfull flow. The development of these metrics and the associated ratings method is described in Goater (2005).

For each flow scenario, a value was calculated for each of the five metrics. To do this, each flow scenario was summarized using weekly exceedence distributions composed of 1% exceedence increments. For metrics 1, 2, 3 and 4, the 23 weekly values (i.e. one for each of growing season weeks 15 to 37) were averaged for each 1% exceedence increment, and then all of the increments in the given criterion's range of influence were averaged together (e.g. the 11 increments from 100 to 90% were averaged for Metric 1). The value for criterion 5 was calculated directly from the weekly streamflow datasets.

All possible values for each metric were divided into four impact ranges based on the values for benchmark flow scenarios and for flows along test reaches in the SSRB. Natural flows produced a value of zero for all metrics. IFN recommended flows produced values of -30, -10, -35, 50, and -5, for metrics 1 through 5 respectively. Where metrics scored between the natural and IFN benchmarks, only slight impacts were expected. Beyond this slight impact range, limits for marginal, serious, and extreme impact ranges were defined based on metric values calculated for six test reaches in the SSRB where impacts of actual streamflow alterations on riparian cottonwoods have been documented. The condition of riparian forests along the upper and lower reaches of the Belly, Waterton and St. Mary rivers was interpreted relative to their general requirements for low, moderate, and peak streamflows (Tables 17 and 18). Metric values were calculated for naturalized and recorded streamflow datasets for each of the six reaches (using the period 1959 to 1995 for the Belly, 1965 to 1995 for the Waterton, and 1953 to 1995 for the St. Mary rivers) (Table 19). For each metric, limits for the marginal, serious, and extreme impact ranges were set by correlating the observed condition of riparian forests along each reach relative to their associated metric values (Table 20).

To facilitate the overall ranking of various management scenarios, the values of metrics 1, 2, 4, and 5 were considered together. The value of Metric 3 was omitted because it was contingent on the values of the other metrics (it functions to bridge minimum and moderate flows prescribed by the other metrics). Because the combined impact of the remaining four metrics was not additive (for example, the higher impact of one was not counterbalanced by lower impact of the others), higher impacts were given progressively

heavier weightings. To do this, metric values in the serious and extreme ranges were penalized 10% and 20% respectively and capped at a maximum value of 100. Each metric was then standardized relative to the limit of the slight impact range (the IFN recommendation) and reported as a percent of the maximum possible for that metric. These values were then averaged to produce an overall score that was rated relative to the four impact ranges (defined by similarly standardized values). For illustrative purposes, the four impact ranges were standardized into quarters and the scores were standardized within the resulting 25% intervals. The impact ranges for the combined metrics are summarized in Table 21.

Four management scenarios were analyzed for the Red Deer River. Metrics were calculated and rated using naturalized and scenario-based weekly streamflows from 1928 to 1995 for each of seven reaches. The predominant (average) impact range across the reaches was reported as the overall impact for the given scenario. The values resulting from the calculations at each step for the seven reaches of the Red Deer River are summarized in Table 22. The impact category and description of the rating for each scenario are summarized in Table 23.

Table 17. Implications associated with each impact range relative to the structure, function, and conservation of riparian cottonwood forests.

	Range of impacts correlated with degree of streamflow modification			
	slight	marginal	serious	extreme
Minima: *flows for [illegible] survival & maintenance*	natural levels of occasional drought stress	Increasing frequency and magnitude of acute drought stress resulting in progressive die-back & mortality [illegible]		Failure to sustain tree life
Moderate: *flows for [illegible] growth & development*	normal healthy growth [illegible] populations	Increasing duration of chronic drought stress resulting in declining health & vigour, and leading to die-back & mortality [illegible]		Failure to sustain trees through normal life cycle
Peak: *flows for [illegible] & succession*	normal [illegible] dynamics & forest replenishment	Progressively reduced distribution, structure & dynamics, [illegible] leading to [illegible] populations [illegible] replenishment		Failure of forest renewal & continuity

Table 18. Impacts of historic flow regimes on the condition of riparian forests along the Belly, Waterton and St. Mary rivers (slight, marginal, serious, extreme)

	Belly River		Waterton River		St. Mary River	
(flows)	upper	Lower	upper	lower	upper	lower
Minimum	[illegible]	--	-	--		--
Moderate	[illegible]	--	-	--	[illegible]	--
Peak		-	-	-	-	-

Table 19. Riparian IFN metric values for the six test reaches in the SSRB (values correspond to the impact ranges shown in Table 20).

	Belly River		Waterton River		St. Mary River	
Metric	upper	lower	upper	lower	upper	lower
	-26.8	-83.7	0.0	-83.9	30.7	-90.6
	4.4	-66.4	29.0	-65.7	14.9	-85.7
	-13.3	-63.3	0.0	-60.3	-31.0	-85.5
	26.3	140.5	-0.2	87.1	191.6	274.1
	66.7	-50.0	0.0	-14.3	-45.5	-40.0

Table 20. Impact ranges for each of the five riparian IFN metrics.

Metric	Slight		Marginal		Serious		Extreme	
	0	30	30	40	40	70	70	100
	0	10	10	20	20	50	50	100
	0	25	25	45	45	60	60	100
	10	50	50	60	60	100	100	500
	0	5	5	10	10	65	65	100

Table 21. Impact ranges for the combined riparian IFN metrics.

Combined Metric Ranges	Slight	Marginal		Serious	Extreme
weighted average limits	0	9.2	15.0	51.5	100
uniformly standardized limits	0	25	50	75	100
	(natural)	(IFN)			(max)

Table 17. Implications associated with each impact range relative to the structure, function, and conservation of riparian cottonwood forests.

	Range of impacts correlated with degree of streamflow modification		
	slight	marginal	extreme
Minima: *flows for cottonwood survival & maintenance*	natural levels of occasional drought stress	Increasing frequency and magnitude of acute drought stress, resulting in progressive die back & mortality *note: individuals in marginal areas, or those lacking well-established root systems (seedlings) will be impacted first*	failure to sustain tree life
Moderate: *flows for cottonwood growth & development*	normal, healthy growth across the population	Increasing duration of chronic drought stress, resulting in declining health & resilience, and leading to die back & mortality *note: individuals that are at higher elevations, or are less established will be impacted first*	failure to sustain tree vigor through natural life cycle
Peak: *flows for cottonwood recruitment & succession*	normal, healthy system dynamics & forest replenishment	Progressively reduced disturbance regime & channel dynamics, leading to fewer seedling recruitment events & inadequate population replenishment	failure to balance population mortality

Table 18. Impacts of historic flow regimes on the condition of riparian forests along the Belly, Waterton and St. Mary rivers (+ = slight, +/- = marginal, - = serious, -- = extreme).

	Belly River		Waterton River		St. Mary River	
(flows)	upper	Lower	upper	lower	upper	lower
Minima	+	--	+	--	+/-	--
Moderate	+	--	+	--	+/-	--
Peak	+/-	[illegible]	+	[illegible]	[illegible]	[illegible]

Table 19. Riparian IFN metric values for the six test reaches in the SSRB (colors correspond to the impact ranges shown in Table 20).

	Belly River		Waterton River		St. Mary River	
Metric	upper	lower	upper	lower	upper	lower
1	-26.8	-83.7	0.0	-83.9	-30.7	-90.6
2	4.4	-66.4	29.0	-65.7	-14.9	-85.7
3	-13.3	-63.3	0.0	-60.3	-31.0	-85.5
4	26.3	140.5	-0.2	87.1	191.6	274.1
5	-6.7	[illegible]	0.0	[illegible]	[illegible]	[illegible]

Table 20. Impact ranges for each of the five riparian IFN metrics.

Metric	Slight	Marginal	[illegible]	Extreme
1	0 > -30	-30 ≥ -40	-40 > -70	-70 ≥ -100
2	0 > -10	-10 ≥ -20	-20 > -50	-50 ≥ -100
3	0 > -35	-35 ≥ -45	-45 > -60	-60 ≥ -100
4	0 < 50	50 ≤ 60	60 < 100	100 ≤ 500
5	0 > -5	-5 ≥ -10	-10 > -65	-65 ≥ -100

Table 21. Impact ranges for the combined riparian IFN metrics.

Combined Metric Ranges	Slight		Marginal		[illegible]		Extreme	
weighted average limits:	0		-9.2		-15.0		-51.5	-100
quarterly standardized limits:	0		-25		-50		-75	-100
	(natural)		(IFN)					(max)

Table 22. Riparian impact rating calculation tables. Cell colors indicate the associated impact category: green = slight, yellow = marginal, red = serious, black = extreme. Abbreviations for the SSRB test reaches are US, LS, UB, LB, UW and LW for the upper and lower St. Mary, Belly and Waterton rivers, respectively.

[illegible]	25.0	[illegible]	75.0	100		
0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.0	25.0	25.0	25.0	25.0	25.0	25.0
77.1	20.0	[illegible]	0.0	65.4		

Table 22. Riparian impact rating calculation tables. Cell colors indicate the associated impact category: green=slight, yellow=marginal, red=serious, black=extreme. Abbreviations for the SSRB test reaches are US, LS, UB, LB, UW and LW for the upper and lower St. Mary, Belly and Waterton rivers, respectively.

Raw Metric Values:
Impact range transitions (Slight/Marginal/Serious/Extreme)

Metric	Min	S/M	M/S	S/E	Max
1	0	30	40	70	100
2	0	10	20	50	100
3	0	35	45	60	100
4	0	50	60	100	500
5	0	5	10	65	100
Ave					

with Penalties (serious=10% & extreme=20%)
and capped to a maximum value of 100

Standardized to Base Score (IFN=S/M)

Metric	Min	S/M	M/S	S/E	Max
1	0.0	1.0	1.3	2.3	3.3
2	0.0	1.0	2.0	5.0	10.0
3					
4	0.0	1.0	1.2	2.0	10.0
5	0.0	1.0	2.0	13.0	20.0
Ave	0.0	1.0	1.6	5.6	10.8

Proportion of maximum standardized score (%)

Metric	Min	S/M	M/S	S/E	Max
1	0.0	30.0	40.0	70.0	100
2	0.0	10.0	20.0	50.0	100
3					
4	0.0	10.0	12.0	20.0	100
5	0.0	5.0	10.0	65.0	100
Ave	0.0	9.2	15.1	51.5	100
standardized 25% groups:	[illegible]	[illegible]	50.0	[illegible]	[illegible]

1) Natural Flow

Raw metric values:

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ave							

With penalties:

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Standardized:

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3							
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ave	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Proportion of maximum:

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1	
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
3								
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Ave	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
standardized to 25% groups:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0

3) Instream Flow Need

Raw metric values:

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1
1	30.0	30.0	30.0	30.0	30.0	30.0	30.0
2	10.0	10.0	10.0	10.0	10.0	10.0	10.0
3	35.0	35.0	35.0	35.0	35.0	35.0	35.0
4	50.0	50.0	50.0	50.0	50.0	50.0	50.0
5	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Ave							

With penalties:

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1
1	30.0	30.0	30.0	30.0	30.0	30.0	30.0
2	10.0	10.0	10.0	10.0	10.0	10.0	10.0
3	35.0	35.0	35.0	35.0	35.0	35.0	35.0
4	50.0	50.0	50.0	50.0	50.0	50.0	50.0
5	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Standardized:

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3							
4	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Ave	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Proportion of maximum:

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1	
1	30.0	30.0	30.0	30.0	30.0	30.0	30.0	
2	10.0	10.0	10.0	10.0	10.0	10.0	10.0	
3								
4	10.0	10.0	10.0	10.0	10.0	10.0	10.0	
5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
Ave	9.2	9.2	9.2	9.2	9.2	9.2	9.2	
standardized to 25% groups:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.0

Test Reaches in the SSRB (for calibration)

Raw metric values:

Metric	US	LS	UB	LB	UW	LW
1	30.7	90.6	26.8	83.7	0.0	83.8
2	14.9	85.7	4.4	66.4	0.0	65.7
3	31.0	85.5	13.3	63.3	0.0	60.3
4	191.6	274.1	26.3	140.5	0.2	87.1
5	45.5	40.0	6.7	50.0	0.0	14.3
Ave						

With penalties:

Metric	US	LS	UB	LB	UW	LW
1	30.7	100	26.8	100	0.0	100
2	14.9	100	4.4	79.7	0.0	78.8
3	31.0	100	13.3	76.0	0.0	72.4
4	100	100	26.3	100	0.2	95.8
5	50.1	44.0	6.7	55.0	0.0	15.7

Standardized:

Metric	US	LS	UB	LB	UW	LW
1	1.0	3.3	0.9	3.3	0.0	3.3
2	1.5	10.0	0.4	8.0	0.0	7.9
3						
4	2.0	2.0	0.5	2.0	0.0	1.9
5	10.0	8.8	1.3	11.0	0.0	3.1
Ave	3.6	6.0	0.8	6.1	0.0	4.1

Proportion of maximum:

Metric	US	LS	UB	LB	UW	LW
1	30.7	100	26.8	100	0.0	100
2	14.9	100	4.4	79.7	0.0	78.8
3						
4	20.0	20.0	5.3	20.0	0.0	19.2
5	50.1	44.0	6.7	55.0	0.0	15.7
Ave	33.5	55.7	7.4	56.1	0.0	37.6
standardized to 25% groups:	62.6	[illegible]	20.0	77.3	0.0	[illegible]

Table 22. (continued) Riparian impact rating calculation tables

[illegible]	25.0		75.0	100.0		
	6.5			6.1		0.8
50.5	51.5	52.4	52.4	55.0	55.6	55.6
63.3	69.8	52.9	51.8	54.2	-	57.0
51.1	50.2	52.1	54.2	57.5	57.3	60.4

Table 22. (continued) Riparian impact rating calculation tables.

	Raw Metric Values Impact range transitions (Slight/Marginal/Serious/Extreme)					Standardized to Base Score (IFN=S/M)					Proportion of maximum standardized score (%)				
Metric	Min	S/M	M/S	S/E	Max	Min	S/M	M/S	S/E	Max	Min	S/M	M/S	S/E	Max
1	0.0	30.0	40.0	70.0	100.0	0.0	1.0	1.3	2.3	3.3	0.0	30.0	40.0	70.0	100.0
2	0.0	10.0	20.0	50.0	100.0	0.0	1.0	2.0	5.0	10.0	0.0	10.0	20.0	50.0	100.0
3	0.0	35.0	45.0	60.0	100.0										
4	0.0	50.0	60.0	100.0	500.0	0.0	1.0	1.2	2.0	10.0	0.0	10.0	12.0	20.0	100.0
5	0.0	5.0	10.0	65.0	100.0	0.0	1.0	2.0	13.0	20.0	0.0	5.0	10.0	65.0	100.0
Ave						0.0	1.0	1.6	5.6	10.8	0.0	9.2	15.1	51.5	100.0
										standardized 25% groups	0.0	25.0	50.0	[illegible]	[illegible]

with Penalties (serious=10% & extreme=20%) and capped to a maximum value of 100

2) Present Use of Existing Licenses

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	
1		18.5			16.6		0.0		18.5			16.6		0.0		0.6			0.6		0.0		18.5			16.6		0.0	
2		0.0			0.2		0.0		0.0			0.2		0.0		0.0			0.0		0.0		0.0			0.2		0.0	
3		9.6			9.2		0.0		9.6			9.2		0.0															
4		20.8			20.0		6.6		20.8			20.0		6.6		0.4			0.4		0.1		4.2			4.0		1.3	
5		0.0			0.0		0.0		0.0			0.0		0.0		0.0			0.0		0.0		0.0			0.0		0.0	
Ave																0.3			0.2		0.0		2.4			2.2		0.3	
																					standardized to 25% groups		[illegible]			[illegible]		[illegible]	4.5

4) Increased Use of Existing Licenses

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	
1	20.4	23.6	39.5	39.3	54.9	46.3	51.1	20.4	23.6	39.5	39.3	60.4	50.9	56.2	0.7	0.8	1.3	1.3	2.0	1.7	1.9	20.4	23.6	39.5	39.3	60.4	50.9	56.2	
2	0.0	7.1	5.2	5.1	20.8	9.5	11.9	0.0	7.1	5.2	5.1	22.9	9.5	11.9	0.0	0.7	0.5	0.5	2.3	1.0	1.2	0.0	7.1	5.2	5.1	22.9	9.5	11.9	
3	18.2	17.5	25.5	25.3	33.1	26.8	28.0	18.2	17.5	25.5	25.3	33.1	26.8	28.0															
4	34.0	23.7	35.9	35.9	48.1	37.2	37.2	34.0	23.7	35.9	35.9	48.1	37.2	37.2	0.7	0.5	0.7	0.7	1.0	0.7	0.7	6.8	4.7	7.2	7.2	9.6	7.4	7.4	
5	25.0	25.0	25.0	25.0	20.0	28.6	28.6	27.5	27.5	27.5	27.5	22.0	31.5	31.5	5.5	5.5	5.5	5.5	4.4	6.3	6.3	27.5	27.5	27.5	27.5	22.0	31.5	31.5	
Ave															1.7	1.9	2.0	2.0	2.4	2.4	2.5	15.8	17.2	18.6	18.5	22.3	22.3	23.3	
																					standardized to 25% groups	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53.2

5) New Licenses with High WCO

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	
1	20.8	20.0	34.2	35.0	50.3	42.2	52.1	20.8	20.0	34.2	35.0	55.3	46.4	57.3	0.7	0.7	1.1	1.2	1.8	1.5	1.9	20.8	20.0	34.2	35.0	55.3	46.4	57.3	
2	0.0	0.0	10.0	1.6	17.7	6.8	16.2	0.0	0.0	10.0	1.6	17.7	6.8	16.2	0.0	0.0	1.0	0.2	1.8	0.7	1.6	0.0	0.0	10.0	1.6	17.7	6.8	16.2	
3	10.5	12.8	22.1	24.9	33.1	26.8	33.0	10.5	12.8	22.1	24.9	33.1	26.8	33.0															
4	23.6	20.0	35.9	42.6	58.0	45.5	55.3	23.6	20.0	35.9	42.6	58.0	45.5	55.3	0.5	0.4	0.7	0.9	1.2	0.9	1.1	4.7	4.0	7.2	8.5	11.6	9.1	11.1	
5	62.5	75.0	25.0	25.0	20.0	14.3	28.6	68.8	90.0	27.5	27.5	22.0	15.7	31.5	13.8	18.0	5.5	5.5	4.4	3.1	6.3	68.8	90.0	27.5	27.5	22.0	15.7	31.5	
Ave															3.7	4.8	2.1	1.9	2.3	1.6	2.7	34.4	44.0	19.3	17.7	21.2	14.5	25.2	
																					standardized to 25% groups	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47.8	[illegible]	56.6

6) New Licenses with Proposed WCO

Metric	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD7	RD6	RD5	RD4	RD3	RD2	RD1	
1	21.9	17.0	30.7	35.5	49.5	40.7	48.6	21.9	17.0	30.7	35.5	54.5	44.8	53.5	0.7	0.6	1.0	1.2	1.8	1.5	1.8	21.9	17.0	30.7	35.5	54.5	44.8	53.5	
2	0.0	0.0	3.6	13.4	30.5	19.6	31.4	0.0	0.0	3.6	13.4	33.6	19.6	34.5	0.0	0.0	0.4	1.3	3.4	2.0	3.5	0.0	0.0	3.6	13.4	33.6	19.6	34.5	
3	17.5	17.3	27.8	34.5	44.5	38.6	46.3	17.5	17.3	27.8	34.5	44.5	38.6	50.9															
4	51.3	31.0	47.8	58.9	76.6	64.0	73.0	51.3	31.0	47.8	58.9	84.3	70.4	80.3	1.0	0.6	1.0	1.2	1.7	1.4	1.6	10.3	6.2	9.6	11.8	16.9	14.1	16.1	
5	25.0	25.0	25.0	25.0	20.0	28.6	28.6	27.5	27.5	27.5	27.5	22.0	31.5	31.5	5.5	5.5	5.5	5.5	4.4	6.3	6.3	27.5	27.5	27.5	27.5	22.0	31.5	31.5	
Ave															1.8	1.7	2.0	2.3	2.8	2.8	3.3	16.7	15.4	18.1	21.2	26.0	25.7	30.3	
																					standardized to 25% groups	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54.7

Table 23. Riparian Vegetation impact ratings of six alternative flow scenarios for the Red Deer River

Scenario	Impact
1) Natural Flow	**Slight**
Natural rates of cottonwood regeneration and growth occur. Riparian condition may be affected by land use activities.	
2) Present Use of Existing Licenses	**Slight**
No detectable change from natural cottonwood community attributable to flow modification. Current riparian condition may be below natural levels due to local land management.	
3) Instream Flow Need	**Slight**
Measurable reduction in cottonwood abundance and age structure due to flow modification. Riparian ecosystem sustained over long-term.	
4) Increased Use of Existing Licenses	**Serious (marginally)**
Measurable reduction in cottonwood abundance and age structure due to flow modification. Increased drought stress due to reductions in low flow. Reduction of flow-dependent regeneration events may not be adequate to ensure long-term sustainability of cottonwood community along some reaches.	
5) New Licenses with High WCO	**Serious**
Inadequate flow-dependent regeneration events to ensure long-term sustainability of cottonwood community. Forest cover reduced in downstream reaches due to flow alteration. Land use practices can contribute to riparian degradation.	
6) New Licenses with Proposed WCO	**Serious**
Inadequate flow-dependent regeneration events to ensure long-term sustainability of cottonwood community. Forest cover reduced in downstream reaches due to flow alteration. Land use practices can contribute to riparian degradation.	

4. Impact ratings for Channel Maintenance

The flow ranges required by channel maintenance IFN were analyzed for each scenario. Changes in the durations and frequencies of these flows relative to natural conditions were used to help subjectively estimate the types and severity of expected impacts. The impact category and description of the rating for each scenario are summarized in Table 24.

Table 24. Channel maintenance impact ratings of six alternative flow scenarios for the Red Deer River.

Scenario	Impact
1) Natural Flow	**Slight**
Sediment transport balanced to maintain natural channel shape and meandering process.	
2) Present Use of Existing Licenses	**Slight**
No detectable change in channel shape, gradient or rate of meandering attributable to flow modification.	
3) Instream Flow Need	**Slight**
Sediment transport balanced over the long term with limited effect on natural channel shape and meandering processes.	
4) Increased Use of Existing Licenses	**Marginal**
5) New Licenses with High WCO	**Marginal**
Reduced overbank flows and sediment transport affects channel shape and meandering processes. Fewer flushing flows contribute to lowered water quality and fisheries spawning success.	
6) New Licenses with Proposed WCO	**Marginal**
Reduced overbank flows and sediment transport affects channel shape and meandering processes. Fewer flushing flows contribute to lowered water quality and fisheries spawning success.	

Table 23. Riparian Vegetation impact ratings of six alternative flow scenarios for the Red Deer River.

Scenario	Impact
1) Natural Flow	
Natural rates of cottonwood regeneration and growth occur. Riparian condition may be affected by land use activities.	
2) Present Use of Existing Licenses	
No detectable change from natural cottonwood community attributable to flow modification. Current riparian condition may be below natural levels due to local land management.	
3) Instream Flow Need	**Slight**
Measurable reduction in cottonwood abundance and age structure due to flow modification. Riparian ecosystem sustained over long-term.	
4) Increased Use of Existing Licenses	**Serious (marginally)**
Measurable reduction in cottonwood abundance and age structure due to flow modification. Increased drought stress due to reductions in low flow. Reduction of flow-dependent regeneration events may not be adequate to ensure long-term sustainability of cottonwood community along some reaches.	
5) New Licenses with High WCO	**Serious**
Inadequate flow-dependent regeneration events to ensure long-term sustainability of cottonwood community. Forest cover reduced in downstream reaches due to flow alteration. Land-use practices can contribute to riparian degradation.	
6) New Licenses with Proposed WCO	**Serious**
Inadequate flow-dependent regeneration events to ensure long-term sustainability of cottonwood community. Forest cover reduced in downstream reaches due to flow alteration. Land-use practices can contribute to riparian degradation.	

4. Impact ratings for Channel Maintenance:

The flow ranges required by channel maintenance IFN were analyzed for each scenario. Changes in the durations and frequencies of these flows relative to natural conditions were used to help subjectively estimate the types and severity of expected impacts. The impact category and description of the rating for each scenario are summarized in Table 24.

Table 24. Channel maintenance impact ratings of six alternative flow scenarios for the Red Deer River.

Scenario	Impact
1) Natural Flow	[redacted]
Sediment transport balanced to maintain natural channel shape and meandering process.	
2) Present Use of Existing Licenses	[redacted]
No detectable change in channel shape, gradient or rate of meandering attributable to flow modification.	
3) Instream Flow Need	**Slight**
Sediment transport balanced over the long term with limited effect on natural channel shape and meandering processes.	
4) Increased Use of Existing Licenses	**Marginal**
5) New Licenses with High WCO	**Marginal**
Reduced overbank flows and sediment transport affects channel shape and meandering processes. Fewer flushing flows contribute to lowered water quality and fisheries spawning success.	
6) New Licenses with Proposed WCO	**Marginal**
Reduced overbank flows and sediment transport affects channel shape and meandering processes. Fewer flushing flows contribute to lowered water quality and fisheries spawning success.	

C. Integrated impact rating for the aquatic ecosystem:

The impact ratings from each of the four ecosystem components were considered in producing an integrated impact rating for the aquatic ecosystem (summarized in Tables 25 and 26). Since the impact ratings for each of the four components produced similar ordinal rankings of the scenarios (similar sequence of colors for each row in Table 26), the predominant impact category (slight, marginal, serious, or severe) was used as the overall impact rating.

For descriptive purposes, the four ordinal impact rating categories were arranged to form a continuous scale, and the scenarios were subjectively positioned along it (indicated by the orange arrows at the top of Table 26). To do this, the impact ratings across the four ecosystem components (within each column in Table 26) were considered in estimating the position of each scenario along this hypothetical continuum.

"Natural Flow" was, by definition, rated in the slight impact range, since it would not produce negative impacts on any of the components of the aquatic ecosystem. Natural flows form the baseline condition for this rating scheme as they define the best condition of the slight category; indicating no impact.

The impact of the "Present Use of Existing Licenses" scenario was unanimously rated as slight. No measurable impacts were expected on fish habitat, riparian vegetation, or channel maintenance. The only detectable impact was expected for water quality when low winter flows might not always meet dissolved oxygen guidelines due to current effluent and nonpoint source runoff loadings along the lower reaches. Thus, the "Present Use of Existing Licenses" scenario was ranked at the more negative end of the slight impact category.

The objective of the "Instream Flow Need" scenario was to be fully protective of the aquatic ecosystem. Its impact was unanimously rated as slight. Because it was designed to meet the essential flow requirements of the aquatic ecosystem, this flow scenario was ranked at the transition between the slight and marginal impact categories.

The impact of the "Increased Use of Existing Licenses" scenario was rated from slight to serious depending on the component surveyed. Although water quality guidelines would usually be met, all of the other components expected measurable to severe impacts. Thus, the overall impact to the aquatic ecosystem was ranked at the marginal end of the serious category.

The impacts of the "New Licenses with High WCO" and "New Licenses with Proposed WCO" scenarios were rated as marginal for the water quality and channel maintenance components, and serious for the fish habitat and riparian vegetation components. Although these two scenarios received identical ratings, their rankings differ because the "New Licenses with Proposed WCO" scenario was expected to have slightly more negative consequences since it involved slightly greater flow reductions.

Table 25. Aquatic ecosystem impact ratings of six alternative flow scenarios for the Red Deer River.

Scenario	Impact
1) Natural Flow	[illegible]
Natural populations, habitats and ecosystem functions are maintained at natural levels.	
2) Present Use of Existing Licenses	[illegible]
Some species affected, ecosystem functions are maintained.	
3) Instream Flow Need	**Slight**
Some species measurably affected, ecosystem-level functions are maintained.	
4) Increased Use of Existing Licenses	**Serious (marginally)**
Ecosystem-level functions affected.	
5) New Licenses with High WCO	[illegible]
Measurable decline in condition or abundance of all species dependent on a natural flow regime. Ecosystem-level functions are impaired.	
6) New Licenses with Proposed WCO	[illegible]
Measurable decline in condition or abundance of all species dependent on a natural flow regime. Ecosystem-level functions are impaired.	

Table 26. Summary of estimated effects of river flows on the aquatic environment of the Red Deer River.

(Table on next page)

Table 25. Aquatic ecosystem impact ratings of six alternative flow scenarios for the Red Deer River.

Scenario	Impact
1) Natural Flow	**Slight**
Natural populations, habitats and ecosystem functions are maintained at natural levels.	
2) Present Use of Existing Licenses	**Slight**
Some species affected; ecosystem functions are maintained.	
3) Instream Flow Need	**Slight**
Some species measurably affected; ecosystem level functions are maintained.	
4) Increased Use of Existing Licenses	**Serious (marginally)**
Ecosystem level functions affected.	
5) New Licenses with High WCO	**Serious**
Measurable decline in condition or abundance of all species dependent on a natural flow regime. Ecosystem level functions are impaired.	
6) New Licenses with Proposed WCO	**Serious**
Measurable decline in condition or abundance of all species dependent on a natural flow regime. Ecosystem level functions are impaired.	

Table 26. Summary of estimated effects of river flows on the aquatic environment of the Red Deer River.

Estimated Effects of River Flows on the Aquatic Environment of the Red Deer River

Slight	Marginal	Serious	Extreme

	Natural Flow	Present Use of Existing Licenses	Instream Flow Need	Increased Use of Existing Licenses	New Licenses with High WCO	New Licenses with Proposed WCO
Aquatic Ecosystem	Natural populations, habitats and ecosystem functions are maintained at natural levels.	Some species affected, ecosystem functions are maintained.	Some species measurably affected, ecosystem level functions are maintained.	Ecosystem level functions affected.	Measurable decline in condition or abundance of all species dependent on a natural flow regime. Ecosystem level functions are impaired.	Measurable decline in condition or abundance of all species dependent on a natural flow regime. Ecosystem level functions are impaired.
Water Quality	Flows provide naturally occurring levels of water quality. Desired levels of water quality may not be met due to current loadings.	Most water quality guidelines met through water management. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	Most water quality guidelines met. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	Estimate: Most water quality guidelines met. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	Estimate: Significant increase in duration and extent of dissolved oxygen guideline exceedences in lower reaches in winter months. Potential for temperature guideline exceedences in fall and ammonia exceedences in spring. Potential for increased aquatic weed growth.	Significant increase in duration and extent of dissolved oxygen guideline exceedences in lower reaches in winter months. Potential for temperature guideline exceedences in fall and ammonia exceedences in spring. Potential for increased aquatic weed growth.
Fisheries	Fish populations are at natural levels. Natural population structure, function, and taxonomic integrity preserved.	Undetectable changes to population structure and function. Similar to natural community. Fish populations are fully maintained.	Barely detectable changes to structure and function of the natural population expected. Fish populations are intact and healthy.	Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.
Riparian	Natural rates of cottonwood regeneration and growth occur. Riparian condition may be affected by land use activities.	No detectable change from natural cottonwood community attributable to flow modification. Current riparian condition may be below natural levels due to local land management.	Measurable reduction in cottonwood abundance and age structure due to flow modification. Riparian ecosystem sustained over long-term.	Measurable reduction in cottonwood abundance and age structure due to flow modification. Increased drought stress due to reductions in low flow. Reduction of flow dependent regeneration events may not be adequate to ensure long-term sustainability of cottonwood community along some reaches.	Inadequate flow-dependent regeneration events to ensure long-term sustainability of cottonwood community. Forest cover reduced in downstream reaches due to flow alteration. Land use practices can contribute to riparian degradation.	Inadequate flow-dependent regeneration events to ensure long-term sustainability of cottonwood community. Forest cover reduced in downstream reaches due to flow alteration. Land use practices can contribute to riparian degradation.
Channel Maintenance	Sediment transport balanced to maintain natural channel shape and meandering process.	No detectable change in channel shape, gradient or rate of meandering attributable to flow modification.	Sediment transport balanced over the long term with limited effect on natural channel shape and meandering processes.		Reduced overbank flows and sediment transport affects channel gradient and meandering processes. Fewer flushing flows contribute to lowered water quality and fisheries spawning success.	Reduced overbank flows and sediment transport affects channel gradient and meandering processes. Fewer flushing flows contribute to lowered water quality and fisheries spawning success.
Description	[illegible] **Not under consideration as a management plan option**	[illegible] **Not under consideration as a management plan option**	[illegible] **Not under consideration as a management plan option**	[illegible] **Not under consideration as a management plan option**	[illegible] **Technically possible management option, but future allocations are extremely limited and existing licenses experience increased risk. Not under consideration as a management plan option**	[illegible] **Recommended in draft water management plan**

Estimated Effects of River Flows on the Aquatic Environment of the Red Deer River

Slight	Marginal	Serious	Extreme

	Natural Flow	Present Use of Existing Licenses	Instream Flow Need	Increased Use of Existing Licenses	New Licenses with High WCO	New Licenses with Proposed WCO
Aquatic Ecosystem	Natural populations, habitats and ecosystem functions are maintained at natural levels.	Some species affected, ecosystem functions are maintained.	Some species measurably affected, ecosystem level functions are maintained.	Ecosystem level functions affected.	Measurable decline in condition or abundance of all species dependent on a natural flow regime. Ecosystem level functions are impaired.	Measurable decline in condition or abundance of all species dependent on a natural flow regime. Ecosystem level functions are impaired.
Water Quality	Flows provide naturally occurring levels of water quality. Desired levels of water quality may not be met due to current loadings.	Most water quality guidelines met through water management. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	Most water quality guidelines met. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	Estimate: Most water quality guidelines met. Requires greater than natural flow in winter due to current loadings. Dissolved oxygen guidelines are not always met in lower reaches in winter.	Estimate: significant increase in duration and extent of dissolved oxygen guideline exceedences in lower reaches in winter months. Potential for temperature guideline exceedences in fall and ammonia exceedences in spring. Potential for increased aquatic weed growth.	Significant increase in duration and extent of dissolved oxygen guideline exceedences in lower reaches in winter months. Potential for temperature guideline exceedences in fall and ammonia exceedences in spring. Potential for increased aquatic weed growth.
Fisheries	Fish populations are at natural levels. Natural population structure, function, and taxonomic integrity preserved.	Undetectable changes to population structure and function. Similar to natural community. Fish populations are fully maintained.	Barely detectable changes to structure and function of the natural population expected. Fish populations are intact and healthy.	Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.	Serious decline in fish populations. Wholesale changes in taxonomic composition. Serious alterations from normal densities. Organism condition will be poor. Anomalies may be frequent.
Riparian	Natural rates of cottonwood regeneration and growth occur. Riparian condition may be affected by land use activities.	No detectable change from natural cottonwood community attributable to flow modification. Current riparian condition may be below natural levels due to local land management.	Measurable reduction in cottonwood abundance and age structure due to flow modification. Riparian ecosystem sustained over long-term.	Measurable reduction in cottonwood abundance and age structure due to flow modification. Increased drought stress due to reductions in low flow. Reduction of flow-dependent regeneration events may not be adequate to ensure long-term sustainability of cottonwood community along some reaches.	Inadequate flow-dependent regeneration events to ensure long-term sustainability of cottonwood community. Forest cover reduced in downstream reaches due to flow alteration. Land use practices can contribute to riparian degradation.	Inadequate flow-dependent regeneration events to ensure long-term sustainability of cottonwood community. Forest cover reduced in downstream reaches due to flow alteration. Land use practices can contribute to riparian degradation.
Channel Maintenance	Sediment transport balanced to maintain natural channel shape and meandering process.	No detectable change in channel shape, gradient or rate of meandering attributable to flow modification.	Sediment transport balanced over the long term with limited effect on natural channel shape and meandering processes.		Reduced overbank flows and sediment transport affects channel gradient and meandering processes. Fewer flushing flows contribute to lowered water quality and fisheries spawning success.	Reduced overbank flows and sediment transport affects channel gradient and meandering processes. Fewer flushing flows contribute to lowered water quality and fisheries spawning success.
Description	This is the pattern of river flow that would have occurred along the Red Deer River without any water diversions or other human interventions. The natural flow regime will support the natural riverine ecosystem indefinitely. It therefore provides a baseline against which to compare alterations to flow. Median annual natural discharge: 1,586,657 cubic decameters. **Not under consideration as a management plan option**	This is the pattern of river flow that has occurred over the past 25 years. These are flows that have largely contributed to the current condition of the riverine ecosystem. There are water allocations not presently used to their full extent. As these allocations are used more completely in the future, the riverine ecosystem will continue to change. Even though the Red Deer River is not highly allocated at present, existing flows are often not close to natural flows. This is due to flow control in the spring and augmented flows for much of the winter. Total present allocation: 341,518 cubic decameters Of total, present allocation to irrigation: 69,422 cubic decameters Of total, present allocation to non-irrigation: 272,096 cubic decameters **Not under consideration as a management plan option**	This is the pattern of river flow that is scientifically determined to sustain a substantially natural aquatic ecosystem over the long term. Limitations to providing these flows such as existing allocations and water law are not considered. For the Red Deer River, an additional demand is included in the IFN determination. To assimilate the waste load currently entering the river to desirable levels, minimum winter flows are increased over the IFN requirement to 16 cubic meters per second. **Not under consideration as a management plan option**	This case is the predicted outcome of all existing allocations and other commitments throughout the South Saskatchewan River Basin being used to their fullest practical extent in the future. This case does not include any other proposed allocation increases such as SAWSP within the Red Deer River Basin. This case uses the existing instream objectives in the Red Deer River. • 8.5 cubic meters per second for irrigation licenses (spring, summer, fall) • 4.25 cubic meters per second for non-irrigation licenses (winter) **Not under consideration as a management plan option**	This case is the predicted outcome of the recommended allocation limit (600,000 dam^3) and the instream flow needs used as the water conservation objective (WCO) for the Red Deer River, but only applied to new licenses. Allocations include: - SAWSP - Acadia Valley irrigation project - Non-irrigation demand to the medium projection to 2046. In this situation the WCO would rarely be met to some degree due to existing allocations (including Dickson Dam). Future allocations (including those listed above) would be very limited due to the high risk of water being unavailable, unless a very large amount of storage was available. **Technically possible management option, but future allocations are extremely limited and existing licenses experience increased risk. Not under consideration as a management plan option**	This case is the predicted outcome of the recommended WCO and allocation limit (600,000 dam^3) for the Red Deer River. Allocations include: - SAWSP - Acadia Valley irrigation project - Non-irrigation demand to the medium projection to 2046. Due to existing allocations (including Dickson Dam) the recommended WCO frequently would not be met to some degree. Future allocations would be possible but most licenses, particularly those for year round water use, would require storage. **Recommended in draft water management plan**

LITERATURE CITED:

Addley, C., G.K. Clipperton, T. Hardy, and A.G.H. Locke. 2003. South Saskatchewan River Basin, Alberta, Canada – Fish Habitat Suitability Criteria (HSC) Curves. Alberta Fish and Wildlife Division, Alberta Sustainable Resource Development. Edmonton, Alberta. 63pp.

AGRA Earth and Environmental Limited, Rapid Creek Research Inc., and Madawaska Consulting, 1995. Water quality assessment of the Red Deer River, Alberta: Summary of initial development and calibration of computer model for simulation of instream flow needs. Prepared for Alberta Environmental Protection, Environmental Protection Planning Division, Calgary.

Alberta Environment 1999. Surface water quality guidelines for use in Alberta. Environmental Sciences Division, Environmental Service. 25pp.

Alberta Environment 2001. South Saskatchewan River Basin historical weekly natural flows database 1912 to 1995. Microsoft Access Database Version 2.03. Water Sciences Branch, Edmonton. Compact Disk.

Annear, T., I. Chisholm, H. Beecher, A. Locke, P. Aarrestad, C. Coomer, C. Estes, J. Hunt, R. Jacobson, G. Jobsis, J. Kauffman, J. Marshall, K. Mayes, G. Smith, R. Wentworth, C. Stalnaker. 2004. Instream Flows for Riverine Resource Stewardship, revised edition. Instream Flow Council, Cheyenne, WY. 268pp.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, U.S. Dept. of the Interior, Washington, D.C. Instream Flow Information Paper 12. 248pp.

Brizga, S.O., A.H. Arthington, S.C. Choy, N.M. Craigie, S.J. Mackay, W. Poplawski, B.J. Pusey, and G.L. Werren. 2001. Pioneer Valley Water Resource Plan – Proposed Environmental Flow Performance Measures. Department of Natural Resources and Mines, Queensland, Australia.

Brown, C. and J. King. 2002. Breede River Basin study DRIFT application. Prepared for the Department of Water Affairs and Forestry, South Africa. Draft Report. Report 2 in a three-part Dual Application Series. 66pp + App. (www.southernwaters.co.za)

Clipperton, G.K., R.F. Courtney, T.S. Hardin, A.G.H. Locke, and G.L. Walder. 2002. Highwood River instream flow needs technical working group final report. Alberta Transportation, Edmonton.

Clipperton, G.K., C.W. Koning, A.G.H. Locke, J.M. Mahoney, and B. Quazi. 2003. Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada. Alberta Environment and Alberta Sustainable Resource Development, Pub No. T/719, Calgary, Alberta. 271pp + App.

Geer, W.H. 1983. A method for treatment of data from the instream flow incremental methodology for instream flow determination. Pages 63-97 in C.R. Berry, editor. Proceedings of the Bonneville Chapter of the American Fisheries Society 1983 Annual Meeting, Logan, Utah.

Goater, L.A. 2005. Evaluation for four flow scenarios for riparian poplar establishment, growth, and maintenance along the Red Deer River. Report for Alberta Environment. 30pp.

Golder Associates Ltd. 1999. Red Deer River Instream Flow Needs Study. Prepared for Fisheries Management Division, Alberta Environmental Protection, Cochrane by Golder Associated Ltd., Calgary, Alberta.

Gom, L.A. 2002. Poplar rule curves (PRC): Instream flow needs (IFN) for riparian poplars in the South Saskatchewan River Basin. Part I – Drafting the PRC. *Prepared for*: Alberta Environment, Southern Operations, Lethbridge. 29pp.

Gom, L.A. and J.M. Mahoney. 2002. Poplar rule curves (PRC): Instream flow needs (IFN) for riparian poplars in the South Saskatchewan River Basin. Part II – Verification and revision of the PRC. *Prepared for:* Alberta Environment, Southern Operations, Lethbridge, AB. 86pp.

Grant, P. 1974. Present minimum flow requirements for the Red Deer River. *Prepared for:* Environmental Planning Division, Alberta Environment, Red Deer River Flow Regulation Study. 16pp.

Cordes, L.D., F.M.R. Hughes and M. Getty. 1997. Factors affecting the regeneration and distribution of riparian woodlands along a northern prairie river: the Red Deer River, Alberta, Canada. Journal of Biogeography 24:675-695.

Hughes, F.M.R. 1994. Environmental change, disturbance and regeneration in semi-arid floodplain forests. In: Environmental change in drylands: biogeographical and geomorphological perspectives. John Wiley & Sons Ltd. pp. 321-345.

Mahoney, J.M. and S.B. Rood 1998. Streamflow requirements for cottonwood seedling recruitment: an integrative model. Wetlands 8(4):634-645.

Milhous, R.T., M.A. Updike, and D.M. Schneider. 1989. Physical habitat simulation system reference manual – Version II. U.S. Dept. of the Interior. Fish and Wildlife Service. Washington, D.C. Instream Flow Information Paper No. 26.

North/South Consultants Inc., Clearwater Consultants Inc. and Patricia Mitchell Environmental Consulting. 2007. Information synthesis and initial assessment of the status and health of aquatic ecosystems in Alberta: Surface water quality, sediment quality and non-fish biota. Prepared for Environmental Policy Branch, Alberta Environment, Edmonton, AB. 493 pp. + Appendices.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. Bioscience 47(11): 769-784.

Richter, B.D., J.V. Baumgartner, R. Wigington, and D.P. Braun. 1997. How much water does a river need? Freshwater Biology 37: 231-249.

Richter, B.D. and H.E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. Conservation Biology 14(5):1467-1478.

Rood, S.B. and J.M. Mahoney. 1991. The biology of riparian cottonwood forests in the Oldman River Basin - Oldman River Dam Mitigation Program Downstream Vegetation Project Report - Volume I. Prepared for: Alberta Public Works, Supply and Services.

Shields, A. 1936. Application of similarity principles and turbulence research to bed-load movement. Mitteilungen der preussischen Versuchsanstalt fur Wassen brau und Schiffbaur. W.P. Ott and J.C. Unchelen (trans.), California Institute of Technology, Pasadena. Rep. No. 167.

Stromberg, J.C. and D.T. Patten. 1990. Riparian vegetation instream flow requirements: a case study from a diverted stream in the eastern Sierra Nevada, California, USA. Environmental Management 14(2):185-194.

Stromberg, J.C. and D.T. Patten. 1991. Instream flow requirements for cottonwoods at Bishop Creek, Inyo County, California. Rivers 2(1):1-11.

Stromberg, J.C. and D.T. Patten. 1996. Instream flow and cottonwood growth in the eastern Sierra Nevada of California, USA. Regulated Rivers: Research & Management 12:1-12.

Stromberg, J.C., B.D. Richter, D.T. Patten and L.G. Wolden. 1993. Response of a sonoran riparian forest to a 10-year return flood. Great Basin Naturalist 53(2):118-130.

Taylor, B.R. and B.A. Barton. 1992. Temperature and dissolved oxygen criteria for Alberta fishes in flowing waters. Prepared for Alberta Fish and Wildlife Division, Edmonton, AB. 72pp.

Tessmann, S.A. 1979. Environmental Assessment. In: Reconnaissance Elements of the Western Dakotas Region of South Dakota Study, Technical Appendix E. Water Resources Research Institute, South Dakota University.

U.S. Geological Survey. 1999. Ecological status and trends of the Upper Mississippi River System 1998: A report of the Long Term Resource Monitoring Program. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. April 1999. LTRMP 99-T001. 236 pp.